University of Alberta

The relationship between northern pike (*Esox lucius*) and wood frogs (*Rana sylvatica*) in boreal Alberta

by

Kirsten Claire Norris

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in partial fulfillment of the requirements for the degree of

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Abstract

A number of studies have demonstrated that the stocking of fish into a fishless waterbody can have a negative impact on the local amphibian population. This study focuses on interactions between northern pike (*Esox lucius*) and populations of wood frog (*Rana sylvatica*) in boreal Alberta. In experimental ponds stocked with both northern pike and wood frog tadpoles, northern pike were found to have a negative impact on the activity and survival of wood frog tadpoles to metamorphosis. However, 9 years of monitoring amphibian abundance at a boreal Alberta lake show a different trend. This fishless lake was stocked with northern pike in 2001, but this has not had a visible effect on the adult and metamorph abundance of the local wood frog population. These conflicting results pose a problem when making recommendations for conserving amphibian populations while maintaining recreational fishing opportunities in Alberta.

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CHAPTER 1: General Introduction

Declines in amphibian populations at global and local levels have become a recent concern among ecologists. Wide-scale declines have been attributed to many factors, including habitat destruction/alteration, pollution, increased UV-B radiation, climate change, and invasion or introduction of predators (Blaustein and Wake 1990, Wake 1991, Houlahan et al. 2000). Introduced fish species have reportedly lead to declines in amphibian communities (Macan 1966, Fisher and Shaffer 1996, Hecnar and M'Closkey 1997, Knapp and Matthews 2000, Gillespie 2001, Pilliod and Peterson 2001) and even local extinctions of some amphibian species (Sjögren 1991, Bradford et al. 1993). Because the species still exists elsewhere, local extinction may not appear to be of huge concern; however, the loss of local populations may cause fragmentation of the larger meta-population and reduce opportunities for recolonizations from nearby sources (Wake 1991, Blaustein et al. 1994, Griffiths 1997).

Amphibians may be especially vulnerable to changes to their environmental due to their biphasic lifecycle, which involves an aquatic larval stage, followed by a terrestrial stage. Hence, an amphibian population can be affected by changes or disturbances in both the aquatic and terrestrial environments. Other amphibian characteristics that make them vulnerable to changes in the environment are permeable skin and eggs which are enclosed in a protective jelly instead of a hard shell; both offer little protection to desiccation or contamination (Russell and Bauer 2000).

Some ecologists have questioned the current concern for amphibian declines, suggesting that the declines are merely misinterpretations of fluctuations in amphibian abundance (Wake 1991, Pechmann and Wilbur 1996, Shirose and Brooks 1997, Alford et al. 2001). Others have suggested that more monitoring over time and in areas where information is lacking is necessary before the declines and their causes are understood (Blaustein and Wake 1990). The latter is true of northern populations, such as in the boreal forest ecoregion. While there have been limited studies in the boreal ecoregion (Fournier 1997, Maunder 1997, Mennell 1997), many amphibian studies have focused in more temperate habitats in the southern part of Canada, where the amphibian community is more diverse).

The boreal forest in Alberta is part of a continuous ecozone that spreads across the northern half of Canada. In boreal Alberta, several anuran species occur: the wood frog (*Rana sylvatica*), the boreal chorus frog (*Pseudacris triseriata*), the Canadian toad (*Bufo hemiophrys*), the western toad (*Bufo boreas*) and possibly the northern leopard frog (*Rana pipiens*; Russell and Bauer 2000). All of these species breed in the spring in waterbodies ranging from small ephemeral ponds to large permanent lakes, where larvae remain in the waterbody for several months before metamorphing into a terrestrial juvenile later in the summer.

My work focused specifically on the wood frog, which is abundant in boreal Alberta. The boreal populations of this species are secure (Alberta Environment [AENV]/Alberta Sustainable Resource Development [ASRD] 2001) and both the larvae and adults of this species typically occur in large numbers

(Russell and Bauer 2000) unlike the toad species (Hannon et al. 2002). In addition, wood frogs are relatively easily monitored through trapping, unlike the boreal chorus frog (Dodd 1991, Stevens and Paszkowski 2005), which makes it a practical species to study.

Wood frog adults move from terrestrial overwintering sites into wet breeding areas as soon as the ice begins to melt in early spring (usually late April to early June; Russell and Bauer 2000). In boreal Alberta, a wide range of waterbodies, from small ephemeral ponds to large permanent lakes, are selected as breeding sites (Eaton 2004, Hannon et al. 2002). Ephemeral waterbodies are less likely to contain predators of eggs or larva, such as aquatic invertebrates or fish; however, there is a risk that the pond will dry up before metamorphosis is complete. Periods of drought or dryness can also limit the number of small ephemeral waterbodies available and increase the number of wood frogs using larger lakes for breeding. In boreal Alberta, metamorphed individuals typically emerge from their waterbody from early July to early September, with the bulk of the metamorphs emerging in mid-July to mid-August. The total duration of the larval stage, from hatching to metamorphosis, is approximately 9-15 weeks (Russell and Bauer 2000), so populations of larval wood frogs can be subject to competition or predation in their aquatic environment for a minimum of 3 months.

Fish assemblages in small lakes in boreal Alberta are shaped by a combination of predation, lake isolation, and natural disturbance (i.e., winterkill), resulting in two assemblage types dominated either by large-bodied piscivorous fish (northern pike [*Esox lucius*], yellow perch [*Perca flavescens*]) or small-

bodied fish (fathead minnow [*Pimephales promelas*], brook stickleback [*Culaea inconstans*]; Tonn and Paszkowski 1986, Robinson and Tonn 1989, Tonn et al. 2003). In fact, a survey of 102 small boreal lakes (1.7 to 362 ha) in Alberta found 27% of the lakes to be dominated by large-bodied fish and 52% to contain the small-bodied assemblage; the remaining 21% of the lakes were fishless (W.M. Tonn, unpublished data). Thus, a wood frog choosing to breed in a larger permanent lake increases the likelihood that its eggs and larvae will encounter one of these two fish assemblages. Eaton (2004) explored the relationship between small-bodied fishes and wood frog, finding that abundance of young-of-the-year (YOY) wood frog and small-bodied fish were negatively correlated, and that fathead minnow and brook stickleback have significant negative impacts on wood frog larvae and survival to metamorphosis in experimental ponds. Little information exists on the relationship between large-bodied fish, specifically northern pike, and wood frogs; however, changes in wood frog and piscivorous fish abundance were negatively correlated 50% of the time in three boreal Alberta lakes (Eaton et al. 2005).

Northern pike, and other *Esox* species, have been shown to have a negative effect on both adult and larval amphibians. In Sweden, male spadefoot toads (*Pelobates fuscus*) and male tree frogs (*Hyla arborea*) avoided calling in ponds containing northern pike (Brönmark and Edenhamn 1994, Nyström et al. 2002), and adult populations of the pool frog (*Rana lessonae*) were less dense in ponds containing pike than in ponds without pike (Sjögren 1991). The addition of pike into experimental ponds resulted in almost complete mortality of *Rana*

esculenta tadpoles (Semlitsch 1993). *R. lessonae* and *R. esculenta* tadpoles exhibited anti-predator behaviour (decreased activity and spatial avoidance) when exposed to chemical cues of northern pike (Stauffer and Semlitsch. 1993). Female ovipositing gray treefrogs (*Hyla chrysoscelis*) avoided depositing eggs in ponds inhabited by grass pickerel (another esocid, *E. americanus*; Binckley and Resetarits 2003). Wood frog larvae did not occur in permanent wetlands containing pickerel (*Esox* sp.; Babbitt et al. 2003).

In this thesis, I examine the relationship between northern pike and wood frogs in boreal Alberta using experimental ponds (Chapter 2). I performed a manipulation in which wood frog tadpoles were stocked in ponds at natural densities and exposed to predatory northern pike. Tadpole behaviour, size, and survival to metamorphosis were measured in pond sections with and without pike.

Natural disturbance (i.e., winterkill) and stocking can cause the density of northern pike within a lake to fluctuate. I examined fluctuations in pike density in one boreal lake over a period of 9 years. Using both adult and metamorph wood frog monitoring data collected during this time, I examined whether the changes in pike density have had an effect on the local wood frog population (Chapter 3).

Currently, there is a lack of information on amphibian populations in northern and western Canada. Results from this study will provide insight into some factors affecting boreal anurans, including the effect of stocked populations of northern pike on behaviour and survival of larval, metamorphosing juvenile, and terrestrial adult wood frogs. Stocking of northern pike, while not yet a common management practice in Alberta, may become a regular strategy in the

province which may have negative implications for amphibian populations in the future. In addition, pike-related factors that can affect wood frogs may also impact other boreal amphibian populations, some of which may already be experiencing a decline (e.g., Canadian and western toads; AENV/ASRD 2001). It is expected that research presented in this thesis will be useful in the formulation of appropriate management plans so northern pike will continue to provide recreational fishing opportunities while maintaining healthy populations of Alberta anurans.

Literature Cited:

Alberta Environment (AENV)/Alberta Sustainable Resource Development (ASRD). 2001. The General Status of Alberta Wild Species 2000. AENV/ASRD, Edmonton, Alberta.

Alford, R.A., P.M. Dixon and J.H.K. Pechmann. 2001. Global amphibian population declines. Nature 412: 499-500.

Babbitt, K.J., M.J. Baber and T.L. Tarr. 2003. Patterns of larval amphibian distribution along a wetland hydroperiod gradient. Canadian Journal of Zoology 81: 1539–1552.

Binckley, C.A. and W.J. Resetarits Jr. 2003. Functional equivalence of non-lethal effects: generalized fish avoidance determines distribution of gray treefrog, *Hyla chrysoscelis*, larvae. Oikos 102: 623-629.

Blaustein, A.R. and D.B. Wake. 1990. Declining amphibian populations: a global phenomenon? Trends in Ecology and Evolution 5: 203-204.

Blaustein, A.R., D.B. Wake and W.P. Sousa. 1994. Amphibian declines: judging stability, persistence, and susceptibility of populations to local and global extinctions. Conservation Biology 8: 60-71.

Bradford, D.F., F. Tabatabai and D.M. Graber. 1993. Isolation of remaining populations of the native frog, *Rana muscosa*, by introduced fishes in Sequoia and Kings Canyon National Parks, California. Conservation Biology 7: 882-888.

Brönmark C. and P. Edenhamn. 1994. Does the presence of fish affect the distribution of tree frogs *(Hyla arborea)*? Conservation Biology 8: 841–845.

Dodd, C.K. Jr. 1991. Drift fence-associated sampling bias of amphibians at a Florida sandhills temporary pond. Journal of Herpetology 25: 296-301.

Eaton B.R. 2004. The roles of landscape factors, predation, and demography in the ecology of anurans in boreal Alberta. Ph.D. Thesis, University of Alberta, Edmonton, Alberta , 176pp.

Eaton, B.R., W.M. Tonn, C.A. Paszkowski, A.J. Danylchuk and S.M. Boss. 2005. Indirect effects of fish winterkills on amphibian populations in boreal lakes. Canadian Journal of Zoology 83: 1532-1539.

Fisher, R.N. and H.B. Shaffer. 1996. The decline of amphibians in California's Great Central Valley. Conservation Biology 10: 1387-1397.

Fournier, M.A. 1997. Amphibians in the Northwest Territories. In *Amphibians in Decline. Canadian Studies of a Global Problem*, ed. DM Green. *Herpetological Conservation*, Vol 1: 100-106.

Gillespie G.R. 2001. The role of introduced trout in the decline of the spotted tree frog (*Litoria spenceri*) in south-eastern Australia. Biological Conservation 100: 187-198.

Griffiths, R.A. 1997. Temporary ponds as amphibian habitats. Aquatic Conservation: Marine and Freshwater Ecosystems 7: 119-126.

Hannon, S.J., C.A. Paszkowski, S. Boutin, J. DeGroot, S.E. Macdonald, M. Wheatley and B.R. Eaton. 2002. Abundance and species composition of amphibians, small mammals, and songbirds in riparian forest buffer strips of varying widths in the boreal mixedwood of Alberta. Canadian Journal of Forest Research 32: 1784-1800.

Hecnar, S.J. and R.T. M'Closkey. 1997. The effects of predatory fish on amphibian species richness and distribution. Biological Conservation 79: 123-131.

Houlahan, J.E., C.S. Findlay, B.R. Schmidt, A.H. Meyer and S.L. Kuzmin. 2002. Quantitative evidence for global amphibian population declines. Nature 404: 752-755.

Knapp, R.A. and K.R. Matthews. 2000. Non-native fish introductions and the decline of the mountain yellow-legged frog from within protected areas. Conservation Biology 14: 428-438.

Macan, T.T. 1966. The influence of predation on the fauna of a moorland fishpond. Archiv für Hydrobiologie 61: 432-452.

Maunder, J.E. 1997. Amphibians of Newfoundland and Labrador: status changes since 1983. In *Amphibians in Decline. Canadian Studies of a Global Problem*, ed. DM Green. *Herpetological Conservation.*, Vol 1: 93-99.

Mennell, L. 1997. Amphibians in southwestern Yukon and northwestern British Columbia. In *Amphibians in Decline. Canadian Studies of a Global Problem*, ed. DM Green. *Herpetological Conservation*, Vol 1: 107-109.

Nyström, P., L. Birkedal, C. Dahlberg and C. Brönmark. 2002. The declining spadefoot toad *Pelobates fuscus*: calling site choice and conservation. Ecography 25: 488-498.

Pechmann, J.H.K., and H.M. Wilbur. 1994. Putting declining amphibian populations in perspective: natural fluctuations and human impacts. Herpetologica 50:65-84.

Pilliod, D.S. and C.R. Peterson. 2001. Local and landscape effects of introduced trout on amphibians in historically fishless watersheds. Ecosystems 4: 322-333.

Robinson, C.L.K. and W.M. Tonn. 1989. Influence of environmental factors and piscivory in structuring fish assemblages of small Alberta lakes. Canadian Journal of Fisheries and Aquatic Sciences 46: 81-89.

Russell, A.P. and A.M. Bauer. 2000. The amphibians and reptiles of Alberta: a field guide and primer of boreal herpetology. University of Calgary Press, Calgary.

Shirose, L.J. and R.J. Brooks. 1997. Fluctuations in abundance and age structure in three species of frogs (Anura: Ranidae) in Algonquin Park, Canada, from 1985 to 1993. In *Amphibians in Decline. Canadian Studies of a Global Problem*, ed. DM Green. *Herpetological Conservation*, Vol 1: 206-225.

Semlitsch, D. 1993. Effects of different predators on the survival and development of tadpoles from the hybridogenetic *Rana esculenta* complex. Oikos 67: 40-46.

Sjögren, P. 1991. Extinction and isolation gradients in metapopulations: The case of the pool frog *(Rana lessonae).* Biological Journal of the Linnean Society 42: 135-147.

Stauffer, H.P. and R.D. Semlitsch. 1993. Effects of visual, chemical and tactile cues of fish on the behavioural responses of tadpoles. Animal Behaviour 46: 355-364.

Stevens, C.E. and C.A. Paszkowski. 2005. A comparison of two pitfall trap designs in sampling boreal anurans. Herpetological Review 36: 147-149.

Tonn, W.M. and C.A. Paszkowski. 1986. Size-limited predation, winterkill, and the organization of *Umbra-Perca* fish assemblages. Canadian Journal of Fisheries and Aquatic Sciences 43: 194-202.

Tonn, W.M., C.A. Paszkowski, G.J. Scrimgeour, P.K.M. Aku, M. Lange, E.E. Prepas and K. Westcott. 2003. Effects of forest harvesting and fire on fish assemblages in boreal plains lakes: a reference condition approach. Transactions of the American Fisheries Society 132:514–523.

Wake, D.B. 1991. Declining amphibian populations. Science 253: 8.

CHAPTER 2: The impact of northern pike (*Esox lucius*) on the growth and survival of wood frog (*Rana sylvatica*) larvae in experimental ponds in boreal Alberta.

Introduction

The negative impact of a predator on an amphibian larval population can occur directly or indirectly. Direct effects occur when the predator consumes or otherwise injures the amphibian larvae (Morin 1985), while indirect effects can cause behavioural (Kats and Dill 1998) and morphological changes (McCollum and Leimberger 1997), resulting in stress, reduced growth, and decreased survivorship. Predators of amphibian larvae include aquatic macroinvertebrates (Werner 1991, Skelly 1994, Van Buskirk and Yurewicz 1998, Lardner 1998, 2000), crayfish (Fauth 1990, Nyström and Abjörnsson 2000) and other amphibians (Morin 1983, Morin 1985, Puttlitz et al. 1999), as well as fish.

Several studies have reported that predatory fish have a negative impact on the density and diversity of amphibians (Tyler et al. 1998, Pilliod and Peterson 2001, Knapp et al. 2003, Knapp and Matthews 2000, Chalcraft and Resetarits 2003, Hecnar and M'Closkey 1997). Specifically, the introduction of predatory fish has negatively affected the growth rate of larval amphibians (Nyström et al. 2001) and the overall tadpole survivorship (Gillespie 2001). In addition, studies have documented behavioural changes (e.g., reduction of tadpole swimming activity) in the presence of fish (Nicieza 2000, Eklöv and Werner 2000).

In boreal Alberta, wood frogs (*Rana sylvatica*) breed in a variety of wet areas, ranging from small ephemeral ponds to larger, more permanent ponds or lakes (Eaton 2004, Hannon et al. 2002). While the small ephemeral ponds may not last long enough for metamorphosis to complete, breeding in the larger permanent lakes increases the likelihood of encountering fish. As previously reported, wood frogs choosing to breed in larger permanent lakes may encounter either a small-bodied fish assemblage (i.e., fathead minnow [*Pimephales promelas*] or brook stickleback [*Culaea inconstans*]) or a large-bodied fish assemblage (i.e., northern pike [*Esox lucius*] or yellow perch [*Perca flavescens*]) in boreal Alberta (Robinson & Tonn 1989).

Eaton (2004) investigated interactions between the small-bodied fish assemblage and wood frog tadpoles in an experimental pond system. He found that both fathead minnow and brook stickleback negatively affected the activity of wood frog tadpoles, and the survival of the tadpoles to metamorphosis.

Large-bodied boreal fish, specifically northern pike, are typically thought of as predatory fish; however, studies investigating the impact of pike on wood frog larvae are limited. In a five-year study of boreal lakes inhabited by northern pike, wood frog metamorphs were found to be more abundant following a winterkill 50% of the time (Eaton et al.. 2005). Large-scale fluctuations in pike density at one boreal lake did appear to affect the recruitment of young-of-the-year wood frog metamorphs (Chapter 3). Interestingly, wood frog tadpoles have been found in the stomach of northern pike (Beyerle 1971, Venturelli 2004), indicating that tadpoles may provide another food source for pike.

To examine the effects of northern pike on wood frog larvae, I conducted experiments in man-made ponds in the boreal forest of Alberta. My goals were twofold: a) to assess and document the impact of stocked northern pike on the growth and survivorship of wood frog tadpoles; and b) to examine possible mechanisms behind any patterns in growth or survivorship of tadpoles. Based on information from other fish-amphibian studies, as well as the feeding habits and food selectivity of northern pike, I predicted that the stocking of northern pike would have a negative effect on the growth and survivorship of wood frog tadpoles. Northern pike were expected to feed directly on wood frog tadpoles, increasing mortality of the tadpoles that would result in lower metamorph recruitment. I also expected that tadpoles would reduce their swimming activity in the presence of northern pike, thereby spending less time foraging, resulting in slower growth.

Northern pike are a popular sportfish across Canada. As a result, pike are often considered for stocking into fishless lakes in the boreal ecozone (Saskatchewan Environment 2004, Manitoba Conservation 2005, Alberta Sustainable Resource Development [ASRD] 2006). Understanding the effects that northern pike may have on wood frog tadpoles will be useful when predicting the impact that stocked pike will have on the local amphibian populations and contribute to the conservation of local amphibians. It is hoped that fisheries and wildlife managers will consider the results of this study when investigating areas for fish stocking and implementing local fish management plans.

Methods and Materials

Study Area

The University of Alberta's Meanook Biological Research Station (MBRS; 54° 62' N, 113° 35' W) is located 135 km north of Edmonton within the boreal mixed-wood ecoregion. There are six naturalized ponds on site. These ponds, approximately 30 m long, 12 m wide, and 1.5 m deep, were dug in the 1990s (three in 1991 and three in 1996) and allowed to naturalize over the years with colonization by naturally occurring plant and invertebrate species. These ponds have held various fish species in previous years but had been fishless before the start of this experiment. Natural populations of wood frog, boreal chorus frog (*Pseudacris maculata*) and western toad (*Bufo boreas*) breed successfully in these ponds (C. Paszkowski, pers.obs.). Ponds are used occasionally by other vertebrate species (waterfowl, shorebirds, moose [*Alces alces*]).

Experimental design

This study took place over two summers (2003 and 2004). In 2003, two ponds were used, while in 2004 a third pond was added. Before initiating the experiment in 2003, all ponds were divided into two equal sections using an impermeable polyethylene curtain; the resulting pond halves were approximately 270 m^3 with a water depth of 1.5 m. Two treatments were used in each pond: pike and fishless. Wood frog tadpole populations were established in both sections of each pond (i.e., on both sides of the curtain), while a small population

of northern pike was established on one side of the curtain only (see description below).

Prior to the commencement of each experiment, water from both sides of each pond was drained into a holding dugout. Each pond section was raked to remove leaf litter and debris and make the pond environments more comparable. All ponds were refilled with water from the holding dugout.

Following commencement of the experiment, a silt fence (1 m high) was constructed around each pond to act as a barrier to amphibian movement. This fence prevented access to the ponds by adult amphibians, and confined emerging wood frog metamorphs until they could be sampled.

At the end of the first field season (2003), all fish were removed from the two ponds (see below). At the beginning of the following field season (2004), the ponds were once again drained. The stocking and sampling techniques were the same for both seasons, with a few exceptions noted below.

Tadpole collection and stocking

Prior to the experiment, wood frog egg masses were collected from within the experimental ponds, as well as from nearby ponds and wet areas. Collected egg masses were held for 3-4 weeks in mesh cages within other ponds at MBRS until the tadpoles had hatched and developed to free-swimming stage (Gosner stage 25; Gosner 1960).

Free-swimming wood frog tadpoles were counted and released simultaneously into all pond sections. A subsample of the tadpoles was measured before stocking. In 2003, two size classes of tadpoles were stocked: <15 mm

(range: 10-15 mm total length) and >16 mm (16-22 mm total length). The ratio of smaller vs. larger tadpoles was the same in each pond section - tadpoles were stocked at a ratio of 2.3 small tadpoles to 1 large tadpole. These tadpoles were stocked on June 9, 2003. In 2004, stocked tadpoles were all from the same size class (range: 10-16 mm total length) and these tadpoles were stocked on May 27, 2004 in Ponds 1 and 2, and June 3, 2004 in Pond 3.

Natural densities of wood frog tadpoles have been reported to be very high (ranging from 600 to 8000 tadpoles/m^2; Petranka and Kennedy 1999, Petranka et al.. 1994, Biesterfeldt et al. 1993); however, lower densities have been observed in boreal Alberta (74 tadpoles/m^2; Eaton 2004), and the number of eggs per mass is reported to be smaller in northern populations (Herreid and Kinney 1967). In fact, Eaton (2004) reported that in the experimental ponds at MBRS, stocking densities exceeding 74 tadpoles/m^2 resulted in small, stunted metamorphs. Therefore, to avoid potential density-dependent effects on tadpole or metamorph size, tadpoles were stocked at relatively low densities. Each pond section received at least 3000 wood frog tadpoles (actual tadpole count ranged from 3024-3500 tadpoles/section) resulting in densities of approximately 25 tadpoles/m^2.

Fish collection and stocking

Northern pike used for stocking were collected from nearby lakes (i.e., within 50 km of MBRS) in late May-early June, using gill-nets and fyke nets. Gill nets were set for no longer than 1 hour to prevent accidental death of the fish.

Fish were held in tanks or in holding cages within other dugout ponds at MBRS until stocking.

Prior to stocking, lengths and weights were collected for each fish. A uniquely numbered yellow Floy™ tag was inserted in the dorsal musculature, in front of the dorsal fin of each pike. The yellow tags helped to locate fish visually, once they were stocked in the ponds, and enabled me to identify the fish individually during fish sampling (see below).

Each pond was assigned two treatments: one section was stocked with northern pike (less than 300 mm total length – this length is typical of age-1 fish; Heath and Roff 1996); the other side remained fishless. Northern pike were stocked in each pond section at a biomass density of 0.003-0.004 kg/m^2 (i.e., four fish/section). In 2003, all fish sections were stocked on June 10, one day after tadpole stocking. In 2004, all fish sections were stocked two days after tadpole stocking. Two ponds were stocked with pike on June 2, while a third pond was stocked on June 6.

All ponds contained natural populations of other potential pike prey items (e.g., odonate larvae, ephemeropteran larvae, coleopteran larvae, amphipods, leeches and dipteran larvae). Leeches, a known invertebrate prey of northern pike in boreal lakes (Venturelli 2004), were stocked biweekly in all pike sections to provide a supplemental food source for pike. This assured that pike predation on tadpoles would not be unnaturally high because other prey sources were limited. Leeches were also added to the fishless treatments to maintain a comparable pond environment.

Sampling

Pond Environment

To compare the environmental conditions across ponds, several water quality parameters were measured. Water temperature was recorded daily, from June 9 until August 13 in 2003, and from June 2 until August 12 in 2004, while pH was recorded monthly using a portable pH meter. In 2004, dissolved oxygen (DO) levels were also measured once each month using a portable DO meter. Water samples were collected monthly for total nitrogen (TN) and total phosphorus (TP). TP was analyzed at MBRS, using standard laboratory procedures. TN samples were prepared at MBRS, and then analyzed at the University of Alberta's limnology lab.

Phytoplankton and periphyton are important food sources for wood frog tadpoles, and numerous aquatic invertebrates (Nyström and Abjörnsson 2000, Russell and Bauer 2000, Nyström et al. 2001, Peacor 2002, Brönmark and Hansson 2003). Chlorophyll-*a* is used as a surrogate measure of phytoplankton and periphyton abundance in a sample. Phytoplankton samples were collected monthly using water samples collected from each pond section. The water samples were filtered using glass fibre filters to collect the phytoplankton. Periphyton samples were collected using artificial substrates (0.5 cm diameter acrylic rods) placed vertically approximately 10 cm beneath the water surface in each section. A 2-cm piece of rod was collected every month and the periphyton was collected from the rod by dissolution in ethanol. Both phytoplankton and

periphyton samples were frozen and taken to the University of Alberta's limnology lab for chlorophyll-*a* analysis using standard limnology procedures.

Aquatic macroinvertebrates may act as competitors or predators of wood frog tadpoles, and also provide a food source for pike. To provide an estimate of the abundance among treatments and ponds, aquatic macroinvertebrates were collected using collapsible mesh minnow traps (mesh size: 2 x 4 mm) set overnight in each pond section. Each pond section was trapped twice every two weeks in 2003 (a total of 10 times between June 12 and August 9); and trapped three times every two weeks in 2004 (a total of 16 times between June 3 and August 5). During each trap session, six mesh traps were placed in one pond section - four traps were placed in shallow water (0.3-0.5 m deep) near the water's edge and two additional traps were placed in deeper waters (1-1.5 m deep). After 24 h, the traps were removed and the aquatic macroinvertebrates were identified and classified into one of the following groups: Odonata, Coleoptera, Hemiptera, Ephemeroptera, Amphipoda, Gastropoda and Other (including Trichoptera, Diptera, Acari and Aranea). The invertebrates were released back into their respective pond sections.

Tadpole visual surveys

Visual surveys were performed in all pond sections to compare tadpole abundance between the two treatments, and among all the ponds. Observers would stand approximately 2 m from the pond edge for 1 min, and count the number of wood frog tadpoles they could see. This was repeated on all three sides of the section (total of 3 min per section). Visual surveys were performed

twice daily, once between 0800 and 1200, and again between 1400 and 1700, to account for possible changes in tadpole distribution or activity throughout the day. Water temperature, air temperature, water condition (clear, murky, etc.), cloud cover, and weather were also recorded to help explain unusually low or high tadpole counts. Tadpole surveys began as soon as fish were stocked (June 10 in 2003, June 2/6 in 2004) and continued until no tadpoles were observed, in any pond section, for >7d (July 27, 2003 and July 23, 2004).

Tadpole trapping

To compare growth rate of tadpoles in the two treatments, wood frog tadpoles were trapped using the same collapsible mesh minnow traps used to trap invertebrates (mesh size: 2 x 4 mm). Similar to invertebrate sampling, each pond section was trapped twice every 2 weeks in 2003 (a total of 10 times between June 12 and August 9); and trapped three times every 2 weeks in 2004 (a total of 16 times between June 3 and August 5). During each trapping session six mesh traps were placed in a pond section: four traps in shallow water (0.3-0.5 m deep) along the shoreline and two traps in deeper waters (1-1.5 m deep). After 24 h, traps were removed and tadpoles counted, weighed and classified to development stage. We used the following stages to designate level of development: Stage 1 – tadpole with no hindlimb development (free-swimming stage; Gosner stage 25); Stage 2 – tadpole with hindlimb buds (Gosner stages 26-30); Stage 3 – tadpole with hindlimbs but no digits (Gosner stages 31-36); Stage 4 – tadpole with well-developed hindlimbs with digits (Gosner stages 37-40); Stage 5 – tadpole with hindlimbs with digits, and front limbs (or buds) discernable within the body

(Gosner stage 41); and, Stage 6 – tadpole with front limbs (all limbs developed but animal remains in the water and retains a tail; Gosner stages 42-44; Gosner 1960). Captured tadpoles were returned to their respective pond sections.

Metamorph trapping

Starting in mid-July, pitfall traps were used to collect young-of-the-year wood frogs emerging from the ponds. These data were used to compare abundance and relative size of the metamorphs, as well as timing of metamorphosis, between the two treatments and among pond sections.

Pitfall traps were installed along the inside of the amphibian fence (7 traps/pond section spaced approximately 7 m apart, located approximately 3-5 m from the pond edge). Large metal cans (25 cm deep and 15 cm in diameter) were used as the pitfall and a plastic funnel (12 cm deep and 15 cm in diameter), placed inside the lid of the can, prevented escape. A rock and wet moss were placed inside each trap, to provide moisture and shelter for captured amphibians. In addition, a stick was placed in the pitfall trap to provide a method of escape for any captured small mammals.

Pitfall traps were opened in all sections when wood frog metamorphs were first seen in the shallow water of any pond. In 2003, traps were opened on July 4 and checked daily for metamorphs until August 19, and then sporadically until September 30 (609 trap nights/per pond section). In 2004, traps were opened on July 16, and checked daily for metamorphs until August 12, and then sporadically until October 2 (546 trap nights/per pond section).

Wood frog metamorphs captured were weighed and examined for injury or deformity, before being released 10-20 m outside of the fenced pond.

Fish sampling

The stocked northern pike were visually monitored on a daily basis. Each day, shoreside visual surveys were used to locate the four fish in each pond. The yellow Floy™ tags, inserted within the dorsal musculature, aided in the visual detection of the individual fish.

Each week, gill nets and/or fyke nets were set to collect the fish from one pond section. Fyke nets were set overnight, while gill nets were set during the day. Gill nets were carefully monitored, and never left for longer than 1 h, in order to prevent accidental death of fish. In 2003, northern pike from each pike section were sampled 8 times, from July 3 until October 7. In 2004, northern pike from each pike section were sampled 16 times from June 8 until October 3.

Captured fish were anaesthetized using 5% clove oil dissolved in ethanol, and then weighed to monitor growth. Pike growth was determined by comparing the weight of captured pike at the beginning and end of the summer. The stomachs of the fish were flushed, using a non-lethal gastric lavage technique (Light et al. 1983). Fish were allowed to recover in holding tanks before being released. Stomach contents were preserved and later identified. These samples were used to monitor the diet of the pike during the course of the experiment.

Occasionally, a fish would get trapped in one of the small collapsible mesh traps intended to capture tadpoles or aquatic macroinvertebrates. These

captured fish were also anaesthetized, weighed and had their stomach contents sampled as described above.

Data analysis

Because treatments were paired within ponds, for each pond, a paired t-test was used to compare average or total measures (invertebrate abundance, proportion of tadpoles observed and captured, tadpole weight, proportion of metamorphs emerging, metamorph weight) across treatments. Chi-square goodness of fit tests were used to compare metamorph counts across treatments in each pond. If a trend was observed, resulting probabilities from each test were combined in a meta-analysis using Fisher's method of combining probabilities from independent tests of significance (Sokal and Rohlf 1995). This method adds the logarithms of P-values from each significance test to produce a single chi-square statistic (using the equation $X^2 = -2\sum \ln P$ and 2n degrees of freedom, where n is the total number of independent tests – see Sokal and Rohlf [1995] for a more detailed explanation).

Pond Environment

For each water quality parameter (temperature, pH, DO, TN, TP and chlorophyll-*a* [phytoplankton and periphyton]), the mean was calculated for all measurements taken over the course of the experiment in each pond section. These values were log transformed and analyzed using a one-tailed paired t-test to determine whether the parameter was higher in one of the treatments.

Macroinvertebrate data were pooled for analysis of overall invertebrate abundance and also analyzed separately for each group. Because

macroinvertebrates were trapped twice every 2 weeks in 2003 and three times every 2 weeks in 2004, for each analysis the catch per unit effort (CPUE; number of animals captured per trap night) from every two (2003) or three (2004) trap sessions was used in the analysis. For each pond, CPUE data were log transformed and then analyzed using one-tailed, paired t-tests to determine if CPUE was larger in one of the treatments.

Tadpole surveys

To account for variations in temperature, weather and/or water clarity, which may have affected the daily tadpole count, the maximum daily tadpole count recorded each week was used in analysis. Before analysis, tadpole counts were divided by the original number of stocked tadpoles to obtain the proportion of the original population observed during a survey. Proportion data from each pond were analyzed using paired t-tests.

Tadpole trapping

Because tadpoles were trapped approximately twice every 2 weeks in 2003 and three times every 2 weeks in 2004, the maximum count of tadpoles from every two (2003) or three (2004) trap sessions was used in the analysis to allow for comparisons between years. Before analysis, tadpole counts were divided by the original number of stocked tadpoles to obtain the proportion of the original population observed during a survey. Proportion data from each pond were analyzed using paired t-tests.

Tadpole weights changed over the summer as animals grew and approached metamorphosis; thus, the weights of tadpoles were compared at a

specific development stage. Weight data in each pond were log transformed and compared using independent t-tests for significance.

Metamorph sampling

For each pond section, the number of individuals captured as metamorphs was divided by the number of individuals stocked as tadpoles to give the proportion of stocked individuals surviving to metamorphosis. This proportion was compared across all pond sections using a chi-square goodness of fit test to determine if survival of tadpoles to metamorphosis differed across pond sections. If the proportion of individuals surviving to metamorphosis was determined to be significantly different across pond sections, a chi-square goodness of fit test was performed on each individual pond in both years (i.e. 5 different tests) to determine whether the proportion emerging from each treatment was significantly different.

When comparing metamorph weights, only data collected during the daily pitfall trapping in July and August only was used. For each pond, metamorph weight data were log transformed and compared using independent t-tests for significance.

Fish Sampling

Growth rates of northern pike were calculated by subtracting the initial weight, taken at the time of stocking, from the final weight, taken later in the summer. Only fish whose final weight had been taken more than two months after stocking were used, to estimate growth over a time period longer than two months.

Results from stomach content analysis were analyzed using chi square tests of independence for trends over time.

Results

Pond Environment

Measurements of water quality parameters (temperature, pH, DO, TN, TP and chlorophyll-*a* [phytoplankton and periphyton]) varied across ponds; however, only phytoplankton chlorophyll-*a* was found to be significantly different between treatments (Table 2-1). Maximum daily water temperature increased over the course of both summers, ranging from 12 to 28 °C ($t = 0.42$, df=4, $P = 0.349$). pH levels also increased over the course of the summer and ranged from 7.37 to 9.71 ($t = 0.75$, df=4, $P = 0.248$). DO levels were only measured in 2004. DO levels recorded approximately 0.5 m below surface ranged from 10.00 to 15.32 mg/L ($t = 0.84$, df=4, $P = 0.245$). TN values ranged from 411.19 to 7855.83 µg/L ($t = 0.92$, df=4, $P = 0.205$) and TP values ranged from 5.60 to 65.90 µg/L ($t = 0.64$, df=4, $P = 0.279$). Phytoplankton chlorophyll-*a* concentrations fluctuated over the course of the summer, ranging from 0.63 mg/m^3 to 15.18 mg/m^3 with significantly higher values occurring in the fishless treatment ($t = 2.28$, df=4, $P = 0.042$). Periphyton chlorophyll-*a* concentrations ranged from 0.04 mg/m^3 to 2.34 mg/m^3 ($t = 0.56$, df=4, $P = 0.304$).

Representatives of the following macroinvertebrate orders were sampled from the experimental ponds: Odonata (larva of both dragonflies [Suborder Anisoptera] and damselflies [Suborder Zygoptera]), Coleoptera (adult and larva of Family Dystiscidae), Hemiptera (water striders [Family Gerridae], water boatmen

[Family Corixidae], backswimmers [Family Notonectidae] and the occasional giant water bug [Family Belostomatidae]), Ephemeroptera (mayfly larva), Amphipoda and Gastropoda (snails). Representatives of Trichoptera (caddisfly larva), Diptera (larva), Acari (water mites [Suborder Hydracarina]) and Aranea (water spider [Family Argyronetidae]) were occasionally captured during the macroinvertebrate sampling, but not enough data were available to determine trends in the abundance of these taxa; thus data from these groups were not included in the analysis. Hirudinea (leeches) added to all treatments approximately every two weeks to provide a supplemental food source for the pike, were also sampled but excluded from the statistical analysis. Leeches were, however, observed to be more abundant in the fishless treatment.

In 2003, the macroinvertebrate community was dominated by coleopterans (mostly adult dytiscids) and hemipterids (mostly backswimmers), followed by odonate larva (mostly dragonflies). In 2004, the macroinvertebrate community was dominated by gastropods and odonate larva (both dragonflies and damselflies), followed by coleopterans (mostly adult dytiscids), hemipterids (mostly backswimmers) and amphipods (Figure 2-1).

The mean CPUE from every two trap sessions in 2003 and every three trap sessions in 2004 for all macroinvertebrates ranged from 15 to 53 macroinvertebrates per trap session (Figure 2-1). Overall macroinvertebrate abundance was slightly higher in the fishless treatment; however, this difference was not significant (χ^2=16.59, df=10, P = 0.08). The only individual macroinvertebrate group significantly affected by treatment was Coleoptera

(χ^2=24.52, df=10, P = 0.01). Mean coleopteran CPUE ranged from 2 to 9 coleopterans per trap session and was significantly higher in fishless treatments (ranging from 3 to 9 coleopterans/trap session) than in pike treatments (ranging from 2 to 6 coleopterans/trap session). Mean amphipod CPUE ranged from 1 to 9 per trap session and was slightly higher in the pike treatment, but this difference was not significant (χ^2=16.61, df=10, P = 0.08). Mean odonate CPUE ranged from 2 to 12 odonates per trap session (χ^2=12.84, df=10, P = 0.23). Mean hemipterid CPUE ranged from 5 to 8 hemipterids per trap session (χ^2=10.74, df=10, P = 0.38). Mean ephemeropterid CPUE ranged from 0 to 2 ephemeropterids per trap session (χ^2=9.88, df=8, P = 0.27). Mean gastropod CPUE ranged from 1 to 25 gastropods per trap session (χ^2=13.33, df=10, P = 0.21).

Tadpole surveys

Maximum daily number of tadpoles observed each week during visual surveys in all ponds and treatments ranged from 0 to 542 over six weeks (Figure 2-2). Fewer tadpoles were observed in pike treatment (maximum weekly count = 225) than in the fishless treatment (maximum weekly count = 542). Combining the probabilities from paired t-tests performed on each pond revealed a strong overall treatment effect on the number of tadpoles observed (χ^2= 30.47, df=10, P < 0.001). In addition, in all pike treatments, tadpoles were observed during the first week after fish-stocking; after this time, the number of tadpoles observed dropped considerably. In the fishless treatments, observers consistently noted moderate numbers of tadpoles until week four.

Tadpole trapping

The maximum number of tadpoles trapped in two trap sessions in 2003 and in three trap sessions in 2004 ranged from 0 to 106 (Figure 2-3). The pike treatment had a negative effect on the number of tadpoles trapped, as fewer tadpoles were captured from the pike treatments (maximum number of tadpoles trapped/pond ranged from 1 to 39 per trap session) than the fishless treatments (maximum number of tadpoles trapped/pond ranged from 9 to 106 per trap session) in all ponds in both years (Figure 2-3). Combining the probabilities from paired t-tests performed on each pond revealed a strong overall treatment effect on the number of tadpoles observed (χ^2= 23.53, df=10, $P < 0.009$). In 2003, very few tadpoles were trapped in the pike treatments after sessions 3-4, while in the fishless treatments tadpoles continued to be trapped in trap sessions 5-6. Overall, very few tadpoles were captured from the pike treatments in 2004; however, a similar trend was evident. In the pike treatments, very few tadpoles were trapped after trap sessions 4-6, whereas tadpoles continued to be trapped in sessions 7-9 (and even 10-12 in Ponds 1-04 and 2-04) in the fishless treatments.

The largest sample sizes of tadpoles captured were in development stage 4. Development stage 4 Sample sizes from each treatment, in each pond for each year, ranged from 3 to 237 (Figure 2-4). Upon analysis, the tadpole weights at this stage showed conflicting trends with respect to treatment. Overall, tadpoles captured from all pike treatments weighed significantly less ($\bar{x}$ = 1.54 ± 0.05 g) than tadpoles captured from all fishless treatments ($\bar{x}$ = 1.77 ± 0.03 g; t = 3.34, df = 181, $P < 0.001$); however, this trend was not seen in every pond. In Pond 1-03,

Pond 2-03 and Pond 2-04, tadpoles captured in the pike treatment ($\bar{x}$ = 1.66 ± 0.06 g, 1.39 ± 0.05 g and 0.76 ± 0.13 g, respectively) weighed less than tadpoles captured from fishless treatments ($\bar{x}$ = 2.14 ± 0.03 g, 1.62 ± 0.06 g and 1.57 ± 0.07 g, respectively). T-tests found differences between treatments in these three ponds to be significant (Pond 1-03: t = 6.26, df = 49, $P < 0.000$; Pond 2-03: t = 2.90, df = 97, $P = 0.005$; Pond 2-04: t = 4.72, df = 6, $P = 0.003$). The opposite trend was seen in Pond 1-04 and Pond 3-04; tadpoles from the pike treatments ($\bar{x}$ = 1.96 ± 0.16 g and 1.28 ± 0.39 g, respectively) weighed more than tadpoles from the fishless treatments ($\bar{x}$ = 1.31 ± 0.08 g and $\bar{x}$ = 0.74 ± 0.03 g, respectively). T-tests were also performed on these ponds (Pond 1-04: t = 3.54, df = 27, $P = 0.002$; Pond 3-04: t = 1.26, df = 2, $P = 0.333$). Due to opposing trends in all ponds (as well as the low sample size in two of the ponds [Pond 2-04: n = 6; Pond 3-04: n = 3]), I was unable to conclude whether there was any significant treatment effect on tadpole weight; thus, further analysis (i.e., combining probabilities) was not required.

Metamorph Sampling

Pitfall trapping yielded a total of 825 metamorphs over two years and ranged from 9 to 241 across pond sections (Figure 2-5). The proportion of wood frog tadpoles stocked surviving to metamorphosis differed significantly from the expected (χ^2 = 748.17, df = 9, $P < 0.000$), with a significantly higher number of individuals emerging from the fishless treatments than the pike treatment (χ^2 = 102.38, df = 4, $P < 0.000$).

Four of the five ponds (Pond 1-03, Pond 1-04, Pond 2-04, Pond 3-04) had higher proportions of metamorphs emerging from the fishless treatment than the pike treatment. This difference was significant in Pond 1-03 ($\chi^2 = 26.46$, df = 1, $P < 0.000$), Pond 2-04 ($\chi^2 = 78.89$, df = 1, $P < 0.000$) and Pond 3-04 ($\chi^2 = 6.43$, df = 1, $P = 0.011$), but non-significant in Pond 1-04 ($\chi^2 = 0.18$, df = 1, $P = 0.674$). Pond 2-03 showed the opposite trend with a significant proportion of metamorphs emerging from the pike treatment than the fishless treatment ($\chi^2 = 8.65$, df = 1, $P = 0.003$; Table 2-2). Comparing the metamorph counts across all ponds using a paired one-tailed t-test revealed that although more metamorphs tended to emerge from the fishless sections, treatments did not differ significantly, ($t = 1.63$, df = 4, $P = 0.089$).

Overall recruitment ranged from 0.3 to 7.8% with higher recruitment from the fishless treatment in all ponds except Pond 2-03 (Table 2-2). The first date of metamorphosis was the first day that metamorphs were seen in the shallow water in each pond section. Metamorphosis occurred later in 2004 than in 2003. In 2003, metamorphs in Pond 2-03 first emerged from pike treatment on July 4 while metamorphs first emerged from fishless treatment one day later. In Pond 1-03, metamorphs first emerged from both treatments on the same day (July 5). In 2004, metamorphs first emerged from the fishless treatments on July 16 in all three ponds; in the pike treatments, metamorphs first emerged from Pond 1-04 on July 16, but emerged later in Pond 2-04 and 3-04 (July 18 and July 24, respectively). Recruitment to mid October (i.e., % of stocked tadpoles emerging as metamorphs) in the pond sections ranged from 0.3-7.8%.

When comparing metamorph weights, only metamorphs from the main wave of metamorphs that ended in August were analyzed. Sample sizes from each treatment, in each pond for each year, ranged from 3 to 219, and metamorph weights ranged from 0.31 to 1.39 g (Figure 2-6). Upon analysis, the metamorph weights showed conflicting trends with respect to treatment. Overall, metamorphs captured from all pike treatments weighed significantly less ($\bar{x}$ = 0.66 ± 0.01 g) than metamorphs captured from all fishless treatments ($\bar{x}$ = 0.75 ± 0.01 g; t = 6.90, df = 640, $P > 0.000$); however, this trend was not seen in every pond. In Pond 1-03, metamorphs captured from the pike treatment did weigh significantly less ($\bar{x}$ = 0.53 ± 0.02 g) than metamorphs captured from fishless treatments ($\bar{x}$ = 0.88 ± 0.01 g; t = 13.36, df = 69, $P > 0.000$). However, in Ponds 2-03 and 1-04, metamorphs in the pike treatment weighed significantly more ($\bar{x}$ = 0.67 ± 0.01 g and $\bar{x}$ = 0.91 ± 0.06 g, respectively) than metamorphs captured from the fishless treatment ($\bar{x}$ = 0.63 ± 0.01 g; t = 2.63, df = 372, $P = 0.009$ and $\bar{x}$ = 0.72 ± 0.04 g; t = 2.54, df = 31, $P = 0.016$, respectively). In Ponds 2-04 and 3-04, there was no significant difference between metamorphs in the pike treatment ($\bar{x}$ = 0.80 ± 0.27 g and $\bar{x}$ = 0.71 ± 0.11 g, respectively) and metamorphs captured from fishless treatments ($\bar{x}$ = 0.82 ± 0.02 g; t = 0.20, df = 2, $P = 0.86$ and $\bar{x}$ = 0.70 ± 0.10 g; t = 0.06, df = 18, $P = 0.95$, respectively). Due to these strong opposing trends in all ponds, I was unable to conclude whether there was any significant treatment effect on tadpole weight; thus, further analysis (i.e., combining probabilities) was not required.

There was a significantly negative relationship between metamorph abundance and metamorph weight (using log-transformed data; $R^2 = 0.60$, $P = 0.009$; Figure 2-7). This relationship was stronger in the pike treatments ($R^2 = 0.70$, $P = 0.076$) than in the fishless treatment ($R^2 = 0.30$, $P = 0.339$).

Fish Sampling

Four northern pike were stocked in each pike treatment. In 2003, two pike from pond 2 died over the course of the experiment and were replaced. In 2004, no pike were found dead during the experiment. All recaptured pike in both years increased in weight over the summers (Figure 2-8), with an average growth rate of 1.14 ± 0.32 g/d (range = 0.77 – 1.78 g/day, n = 11 out of 20 stocked pike).

Stomach samples taken from the pike showed a variety in diet among the individual pike and over the course of the summer. Overall, 29 stomach samples were taken from 5 different pike in 2003 and from 12 different pike in 2004. A summary of the stomach samples is shown in Table 2-3. Based on number alone, dipteran larvae (99% *Chaoborus*) and amphipods were the most abundant species found in the stomach samples, followed by odonate larvae, hirudinea and ephemeropteran larvae. Wood frog tadpoles were found in the stomach of one pike in 2003 (July 3, Pond 2-03) and two pike in 2004 (June 10, Pond 3-04 and June 26, Pond 1-04). The species composition of samples collected early (i.e., June – July; n = 21) and late (i.e., October; n = 8) in the season were found to be significantly different ($\chi^2 = 347.49$, df = 6, $P > 0.000$), with zygopteran and ephemeropteran larvae (as well as wood frog tadpoles) more abundant during June - July, and amphipods and chaoborid larvae becoming more important later

on in the season. Anisopteran larvae and hirudinea were common throughout the entire season.

Discussion

In this experiment, northern pike negatively affected the activity of wood frog tadpoles, as well as the number of metamorphs emerging from the fish-inhabited ponds; however, the effect on tadpole growth and metamorph size is unclear.

The presence of northern pike was the main difference between the experimental treatments. There were no significant differences in the pond temperature or chemistry (i.e, pH, TN, TP and DO) between the pike and fishless treatments. Phytoplankton levels were found to be significantly higher in the fishless treatments (as assessed via chlorophyll-*a* concentrations); however, there was no significant difference in the periphyton levels between the pike and fishless treatments.

Similarly, there were no significant differences in overall macroinvertebrate abundance between pike and fishless treatments. Coleopterans were significantly more abundant in the fishless treatment than in the pike treatment; however, no other macroinvertebrate group showed a significant trend in abundance with regards to treatment. Odonate larva (dragonflies and damselflies), dytiscids (mostly adults), hemipterids (mostly backswimmers) and gastropods were the most abundant members of the macroinvertebrate community. Based on casual observation only, leeches, which were added regularly to all sections of ponds to provide a food supplement for the pike,

appeared to be more abundant in the fishless treatments. This is possibly due to predation of leeches by pike in the pike treatments, as leeches were regularly found in the stomach contents of sampled pike. The higher abundance of leeches in the fishless treatments may have had a small impact on the tadpole abundance, as leeches are known to have a negative effect on the development of larval amphibians (Schalk et al. 2002) and, in fact, were observed feeding on tadpoles during the course of this experiment (K. Norris, personal observation).

The presence of northern pike was found to significantly reduce tadpole activity. This was evident by the low numbers of tadpoles observed in the pike treatments during daily surveys, as well as the low numbers of tadpoles captured by mesh traps from the pike treatments, as tadpoles had to be actively swimming to be captured. Macan (1966) introduced brown trout (*Salmo trutta*) into a pond and reported a similar pattern, where tadpoles (*Rana* sp. and *Bufo* sp.), which had been observed swimming throughout the pond prior to fish introduction, disappeared within a few days in the presence of fish. Several studies have reported reduced activity (Nicieza 2000, Eklöv and Werner 2000) and increased spatial avoidance (Eklöv and Werner 2000) by *Rana* tadpoles in the presence of fish predators. Although aquatic vegetation did provide abundant refuge areas within the ponds, my study did not systematically document refuge use or spatial avoidance of predators.

The presence of other aquatic predators reduces tadpole activity and increase use of spatial refuges (Werner 1991, Skelly 1992, Skelly 1994, Van Buskirk and Yurewicz 1998, Puttlitz et al. 1999). Theoretical models of predator-

prey interactions indicate that reduced activity decreases predation risk in two ways (Skelly 1994): less time spent moving reduces the chance of an encounter with a predator; and reduced movement also lessens the chance of visual detection and detection via vibration and the lateral line system by a predator. Other factors have been reported to reduce tadpole activity, including the size and development stage of the tadpoles, and the quality and quantity of food resources (Anholt et al. 2000, Eklöv and Halversson 2000, Eklöv and Werner 2000).

Reduced activity may result in less time foraging for food, which should decrease food intake and could result in slower growth. In fact, smaller sizes and a slower growth rate have been observed in tadpoles of several anuran species in the presence of predators (Nyström at al 2001, Lardner 1998, 2000). Size is important in tadpole survival: larger tadpoles may be less vulnerable to predation and have greater swimming ability, thus enabling them to avoid predation (Semlitsch and Gibbons 1988, Richards and Bull 1990). In the present experiment, the overall trend does suggest that the presence of northern pike had a negative effect on tadpole growth; however, when the data were broken down, this negative effect was only observed in 3 out of the 5 ponds. In fact, different ponds showed such strong opposing trends, that no conclusions could be drawn from the resulting data.

Metamorph recruitment to mid-August (i.e., % of stocked tadpoles emerging as metamorphs) in the pond sections ranged from 0.5-7.8%. These numbers are well within the range of recruitment (0 – 10%) reported in natural anuran populations (Herreid and Kinney 1966, Berven 1990). Significantly fewer

metamorphs were found to emerge from the pike treatments than the fishless treatments in my experiment, suggesting that the presence of northern pike has a negative effect on overall survival of wood frog tadpoles to metamorphosis. Other studies have reported low metamorph density in the presence of predatory fish (Nyström et al. 2001, Pilliod and Peterson 2001).

The presence of predatory fish has also been reported to negatively affect size at metamorphosis in other studies (Nicieza 2000, Nyström et al. 2001), but no clear overall trend was seen in the size of the wood frog metamorphs emerging from the two treatments in this study. However, there was a negative correlation between metamorph weight and density, a relationship that has been documented in other amphibian studies as well (Smith 1983, Martinez et al. 1996, Eaton et al. 2005). Larger metamorphs have higher post-metamorphic survival (Berven 1990, Morey and Reznick 2001), an increased survivorship to maturity (Smith 1987), and overall larger size as an adult (Berven 1990). Larger adult males can displace smaller males attempting to amplex with females and can remain better clasped to females (Berven 1981, Howard and Kluge 1985), while larger females produce more eggs (Howard and Kluge 1985).

The date of metamorphosis varied over year and across pond sections. In 2003, wood frog metamorphs were first observed emerging from all fishless treatments on July 5, and from pike treatments on July 4 and 5. In 2004, the first wood frog metamorphs were observed emerging from the fishless treatments on July 16. Time of metamorphosis in the pike treatments ranged from July 16, 2004 to July 24, 2004. Although predation risk has been reported to prolong larval

period (Babbitt 2001), in this study there was no trend to suggest that tadpoles required a longer period of larval development in pike treatments.

The timing of metamorphosis and mean size of the emerging metamorphs reported in this experiment were comparable to a wood frog population from a large dugout pond also located at MBRS. This local population was sampled daily using pitfall trapping during the months of July and August in 2003 and 2004, as part of the Researching Amphibian Numbers in Alberta [RANA] project (Government of Alberta, Sustainable Resource Development, Fish and Wildlife Division, unpublished data; Wilkinson and Berg 2004, Wilkinson and Kempin 2004, K. Norris unpublished data). Wood frog metamorphs emerging from this dugout in 2003 had a mean weight of 0.86 g (ranging from 0.3-2.0 g, n=838), while in 2004 the mean weight was 1.00 g (ranging from 0.5-2.0, n=256). Metamorphs began emerging earlier in 2003 (July 4) than in 2004 (July 12).

All northern pike that were sampled increased in weight over the course of the summer, indicating that pike were growing and had some prey source within the pond. Three pike had wood frog tadpoles in their stomach (one pike in 2003 [July 3] and two in 2004 [June 10 and June 26]), showing that wood frog tadpoles are a food source for pike. Stomach content analysis found the most abundant prey species (in decreasing abundance) were *Chaoborus* larvae, amphipods, odonate larvae and leeches. Species composition of stomach samples varied over the course of the summer with zygopteran and ephemeropteran larvae, as well as tadpoles, more common in June – July, and amphipods and *Chaoborus* larvae becoming more common in October. This shift in diet is likely explained by the

seasonal shift in prey availability in the ponds themselves. Not surprisingly, due to the leech supplement added to all ponds regularly throughout the summer, leeches remained a constant prey item throughout the season.

Amphipods and odonate (both anisopteran and zygopteran) larvae have been reported as common invertebrate prey in other studies of northern pike diet in fishless waterbodies (Chapman et al. 1989, Beaudoin et al. 1999, Venturelli and Tonn 2005). Leeches and dipteran larvae (Venturelli and Tonn 2005), and ephemeropteran larvae (Chapman et al. 1989) have also been reported to be of importance in the invertebrate diet of pike. Availability of prey items as well as their energy content can impact pike diet. In a pike-only environment, leeches, amphipods and ephemeropterans provide higher energy densities relative to other potential invertebrate prey (Venturelli 2004, and references therein). Using an index of food selection, Venturelli (2004) found pike had a strong positive selection for leeches in pike-only lakes. Beaudoin et al. (1999) found the most important invertebrate prey to be amphipods, odonates and, to a lesser extent, chaoborid larva, using a relative importance index (RI) based on frequency of occurrence, number and mass found in stomach contents.

Conclusion

The results from this experiment clearly indicate that the presence of northern pike reduces wood frog tadpole activity. This trend was strong and was seen in all pike treatments. Reduced activity is expected to reduce tadpole growth rates and result in smaller individuals, although this trend was not clearly evident in all of the pike treatments of the present experiment. Overall metamorph

survivorship was lower in the pike treatments, suggesting that northern pike do limit the ability of wood frog tadpoles to reach metamorphosis. The mechanism for this trend may be a combination of direct predation (wood frog tadpoles were found in the stomachs of two northern pike), and predator-induced reduced activity, allowing for increased mortality due to natural causes (e.g., disease, predation by invertebrates, etc.). No clear trend was observed with regards to the effect of northern pike on tadpole growth or metamorph size, or with regards to length of larval period.

The implication of these results is that wood frog tadpole populations in lakes inhabited by northern pike may be at risk of low overall survival. In years of low precipitation, larger, permanent waterbodies that are more likely to contain populations of large-bodied predatory fish could become important areas for anuran reproduction. The results from this study suggest that the presence of northern pike may negatively affect such wood frog populations.

These results may be applicable to other boreal amphibians. The western toad (*Bufo boreas*), the Canadian toad (*Bufo hemiophrys*), as well as the boreal chorus frog (*Pseudacris maculata*), all inhabit the boreal forest and require waterbodies for egg-laying and larval development, which may or may not contain northern pike. These amphibian species may also be impacted by the stocking of northern pike into boreal lakes. In fact, Eaton et al. (2005) documented very low *Bufo* sp. metamorph abundance following increases in predatory fish abundance. Future studies could investigate the impact of northern pike populations on these amphibian species.

My results are important to consider in sportfish management. Northern pike are a very popular sportfish in the boreal forest, and are often considered for stocking in lakes (and are already used to stock lakes in boreal Saskatchewan and Manitoba; Saskatchewan Environment 2004, Manitoba Conservation 2005). Before stocking a waterbody, I recommend that fisheries managers investigate other species that use these lakes. If the lake is found to be an important breeding site for anuran amphibians like the wood frog, managers might reconsider a stocking program in that area.

Table 2-1: Summary of water quality parameters measured in all ponds over the course of the experiment. Mean values are shown with range in parentheses.

Pond-Year	Treatment	Temperature °C	pH	DO mm/L	TN µg/L	TP µg/L	Chl-*a* (phytoplankton) mg/m^3	Chl-*a* (periphyton) mg/m^3
Pond 1 - 03	pike	19.7 (12 - 26)	8.97 (8.09 - 9.54)	not measured	738.26 (733.05 - 743.46)	32.54 (26.20 - 38.88)	2.71 (1.61 - 3.80)	0.11 (0.08 - 0.14)
	fishless	19.6 (12 - 26)	8.26 (7.87 - 8.77)	not measured	46.05.89 (1362.15 - 7855.63)	64.78 (65.76 - 66.81)	4.71 (3.83 - 5.60)	0.73 (0.18 - 1.23)
Pond 2 - 03	pike	19.8 (12 - 26)	8.64 (7.97 - 9.29)	not measured	875.57 (869.07 - 882.07)	39.60 (39.43 - 39.77)	1.93 (1.83 - 2.03)	0.47 (0.04 - 0.90)
	fishless	20.0 (12 - 26)	9.18 (8.23 - 9.71)	not measured	751.11 (744.05 - 758.12)	33.13 (30.84 - 35.45)	2.25 (1.30 - 3.21)	0.18 (0.14 - 0.21)
Pond 1 - 04	pike	19.7 (12 - 26)	8.06 (7.41 - 8.45)	10.93 (10.83 - 11.04)	665.78 (547.94 - 783.62)	37.13 (18.30 - 65.90)	1.49 (0.90 - 2.33)	0.61 (0.22 - 0.99)
	fishless	19.8 (12 - 26)	8.65 (7.37 - 9.31)	11.00 (10.65 - 11.34)	737.82 (680.08 - 794.56)	28.28 (19.00 - 37.56)	0.82 (0.30 - 1.35)	0.63 (0.20 - 1.07)
Pond 2 - 04	pike	19.9 (12 - 26)	8.61 (8.05 - 8.90)	10.51 (10.00 - 11.02)	740.02 (645.57 - 834.47)	29.25 (28.00 - 30.50)	2.66 (1.81 - 3.57)	1.19 (0.05 - 2.34)
	fishless	19.8 (12 - 26)	8.56 (7.93 - 8.88)	12.79 (11.20 - 14.38)	580.86 (524.17 - 637.57)	29.65 (28.30 - 31.00)	0.58 (0.40 - 0.76)	0.46 (0.52 - 0.40)
Pond 3 - 04	pike	20.0 (14 - 26)	7.84 (7.83 - 7.87)	13.04 (10.76 - 15.32)	494.82 (411.19 - 578.45)	12.40 (5.60 - 19.40)	1.41 (0.63 - 2.49)	0.24*
	fishless	20.1 (11 - 26)	8.43 (7.91 - 8.94)	12.66 (10.97 - 14.35)	536.68 (501.1 - 572.26)	23.37 (11.30 - 35.43)	1.17 (0.86 - 1.48)	0.31*
P-value		0.349	0.248	0.245	0.205	0.279	**0.042**	0.304

* Only one measurement was taken from this pond.

[a] *P*-values were determined for each parameter using a one-tailed paired t-test (see text for details)

Table 2-2. Summary of tadpole stocking, metamorphs captured and date of metamorphosis in pike and fishless treatments. Comparing percent recruitment, four ponds showed a trend of higher proportions of metamorphs emerging from the fishless treatment (significant in three of the four ponds), while one pond (Pond 2-03) showed a higher proportion of metamorphs emerging from the pike treatment (non-significant).

Pond-Year[a]		# tadpoles stocked	# metamorphs captured	% recruitment	X^2	P[b]	first date of metamorphosis
* Pond 1 - 03	pike	3124	60	1.9%	26.46	0.000	July 5
	fishless	3068	**129**	4.2%			July 5
* Pond 2 - 03	pike	3078	**241**	7.8%	8.65	0.003	July 4
	fishless	3100	182	5.9%			July 5
Pond 1 - 04	pike	3500	24	0.7%	0.18	0.674	July 16
	fishless	3500	27	0.8%			July 16
* Pond 2 - 04	pike	3500	9	0.3%	78.89	0.000	July 18
	fishless	3500	**103**	2.9%			July 16
* Pond 3 - 04	pike	3024	16	0.5%	6.43	0.011	July 24
	fishless	3033	**34**	1.1%			July 16

[a] * indicates significant result in independent test.

[b] Probabilities were calculated using a Chi Square Goodness of Fit test

Table 2-3. Number and percent composition of items found in the stomachs of northern pike stocked in experimental ponds in 2003 and 2004. Values are shown for all stomachs sampled, and broken down by time of year (i.e., 'Early' or 'Late') and year. Early stomach samples were taken in mid-summer (June - July) of each year, while 'late' stomach samples were taken in October of each year.

	Stomach item	Number	% Composition
All Fish	Amphipoda	53	12.6
n = 29	Anisopteran larva	9	2.1
	Zygopteran larva	28	6.7
	Chaoboridae larva	289	**68.8**
	Hirudinea	16	3.8
	Ephemeroptera larva	10	2.4
	Other invertebrates	8	1.9
	R. sylvatica tadpoles	7	1.7
	Total items	420	100.0
2003 - 'Early'	Amphipoda	1	5.3
n = 4	Anisopteran larva	2	10.5
	Zygopteran larva	6	**31.6**
	Chaoboridae larva	0	0.0
	Hirudinea	4	21.1
	Ephemeroptera larva	1	5.3
	Other invertebrates	1	5.3
	R. sylvatica tadpoles	4	21.1
	Total items	19	100.0
2003 - 'Late'	Amphipoda	0	0.0
n = 2	Anisopteran larva	0	0.0
	Zygopteran larva	0	0.0
	Chaoboridae larva	0	0.0
	Hirudinea	3	**100.0**
	Ephemeroptera larva	0	0.0
	Other invertebrates	0	0.0
	R. sylvatica tadpoles	0	0.0
	Total items	3	100.0
2004 - 'Early'	Amphipoda	0	0.0
n = 17	Anisopteran larva	3	6.0
	Zygopteran larva	22	**44.0**
	Chaoboridae larva	1	2.0
	Hirudinea	5	10.0
	Ephemeroptera larva	9	18.0
	Other invertebrates	7	14.0
	R. sylvatica tadpoles	3	6.0
	Total items	50	100.0
2004 - 'Late'	Amphipoda	52	14.9
n = 6	Anisopteran larva	4	1.1
	Zygopteran larva	0	0.0
	Chaoboridae larva	288	**82.8**
	Hirudinea	4	1.1
	Ephemeroptera larva	0	0.0
	Other invertebrates	0	0.0
	R. sylvatica tadpoles	0	0.0
	Total items	348	100.0

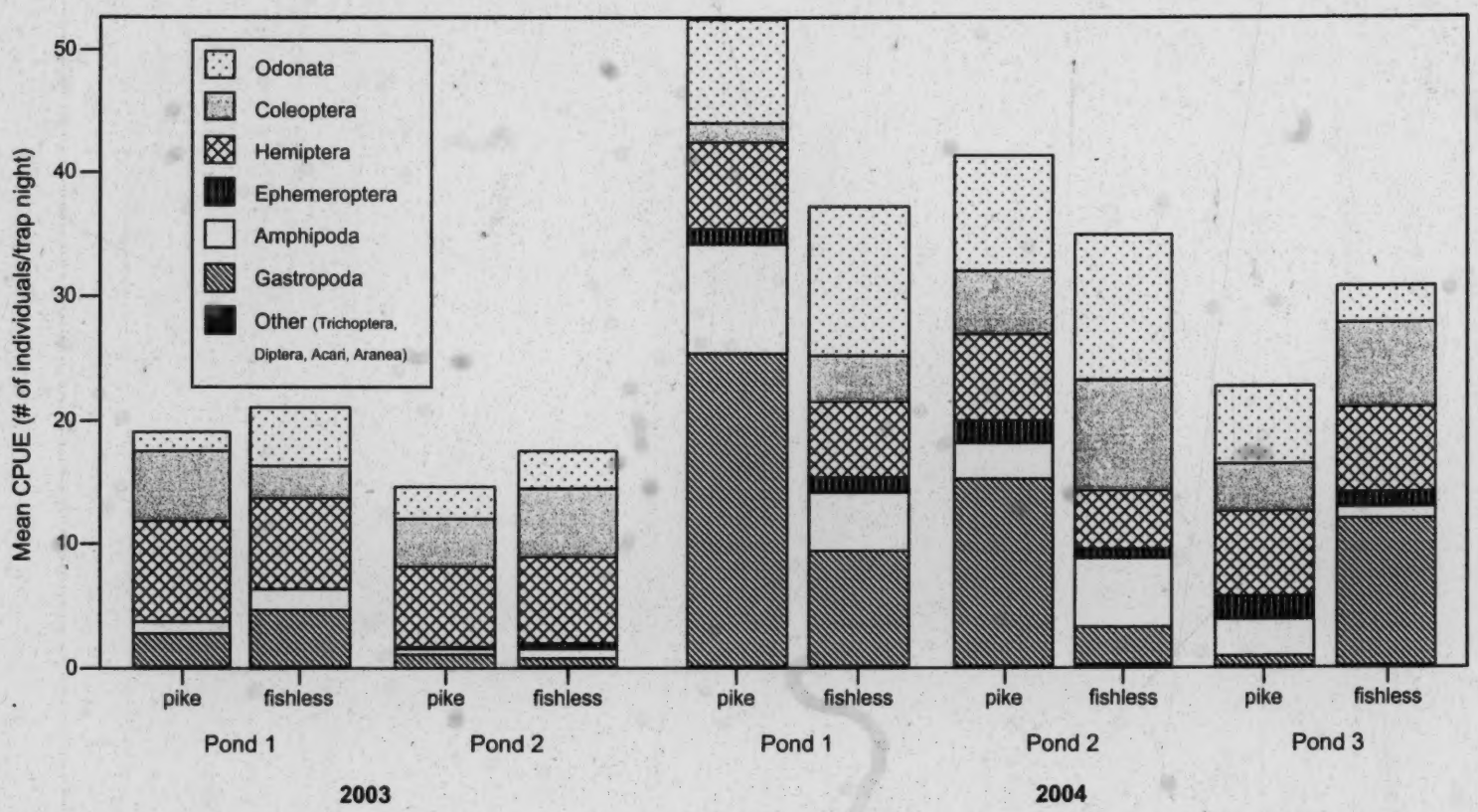

Figure 2-1. The catch per unit effort of macro-invertebrates in 2003 and 2004, in both pike and fishless treatments. See text for significant differences within invertebrate taxa.

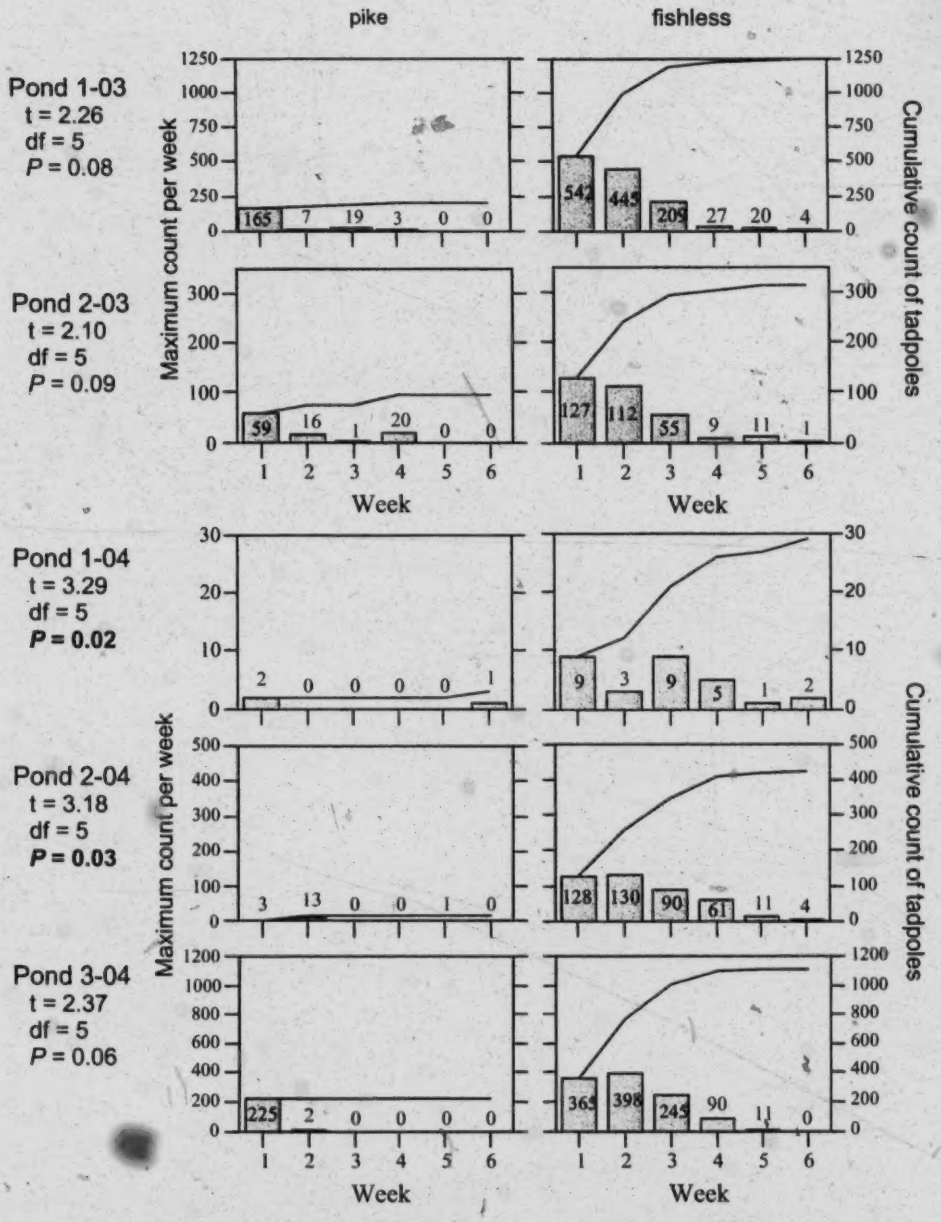

Figure 2-2. The count of tadpoles observed during visual surveys. Bars represent the maximum daily count of tadpoles seen each week, while lines represent the cumulative count of tadpoles observed over the summer. Using paired t-tests, treatment was found to significantly affect the weekly tadpole count in Pond 1-04 and 2-04. Combining probabilities from all 5 ponds showed an overall significant treatment effect ($X^2 = 30.47$, df = 10, $P = 0.001$)

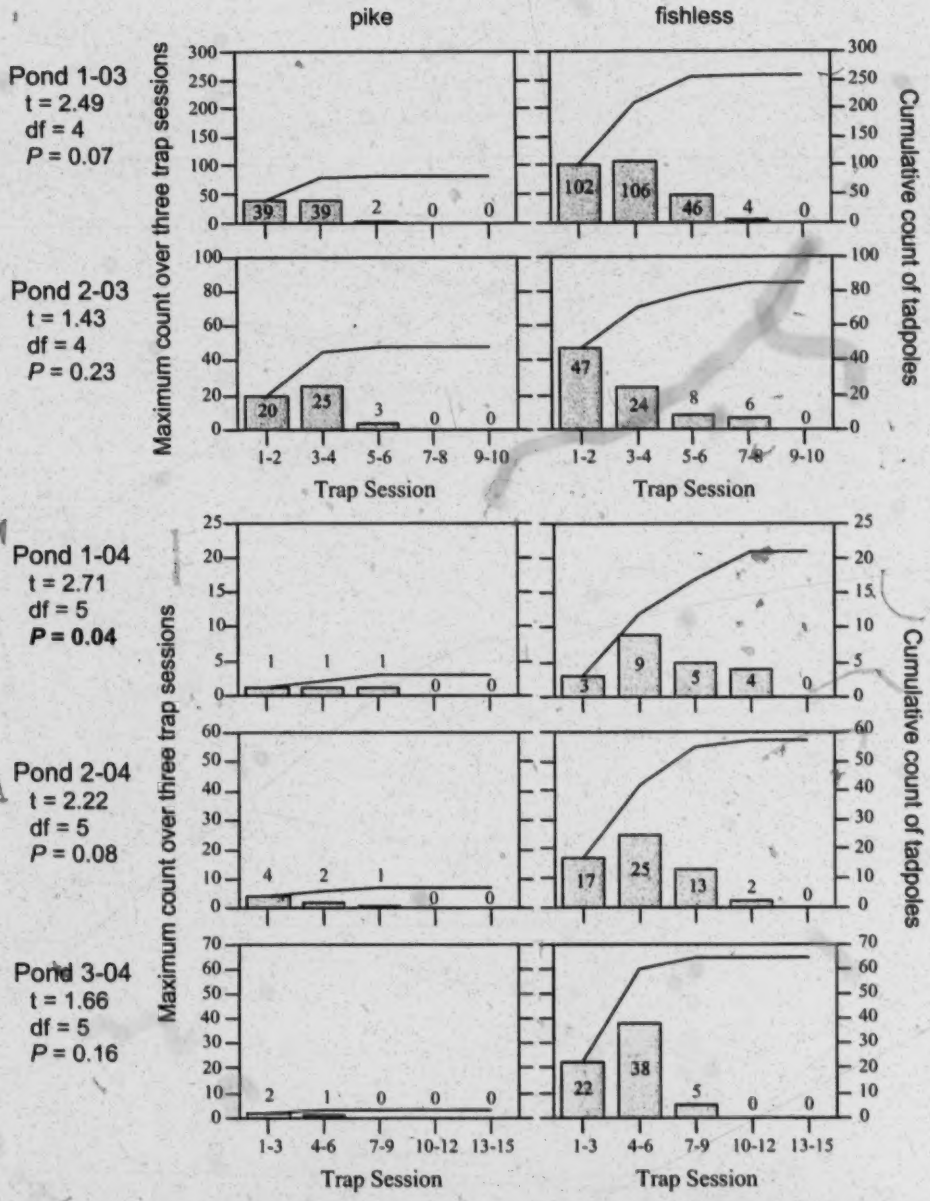

Figure 2-3. The count of tadpoles captured over the course of the study in 2003 and 2004 in both pike and fishless treatments. Bars represent the maximum count of tadpoles captured over two trap sessions in 2003 and three trap sessions in 2004, while lines represent the cumulative count of tadpoles over the summer. Using paired t-tests, treatment was found to significantly affect the number of tadpoles captured in Pond 1-04. Combining probabilities from all 5 ponds showed an overall significant treatment effect ($X^2 = 23.53$, df = 10, $P = 0.009$)

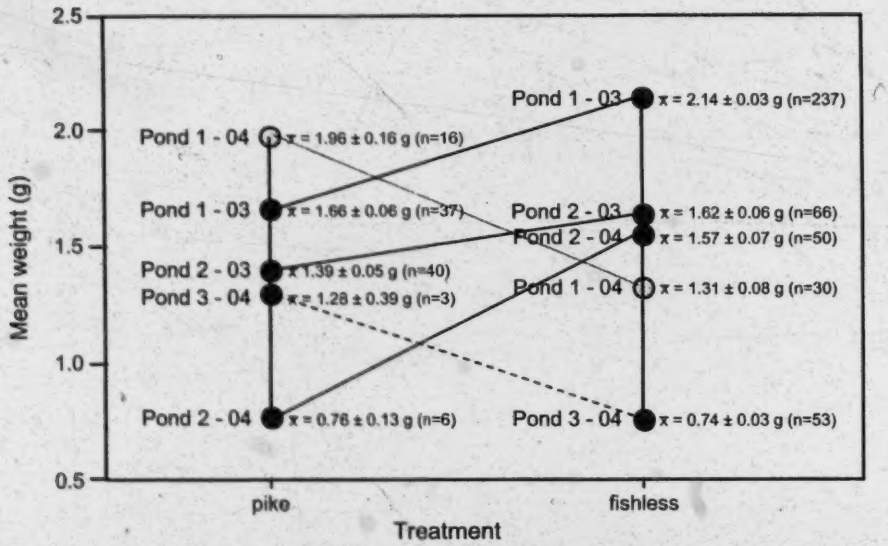

Figure 2-4. The mean weight of tadpoles (at development stage 4), captured in both pike and fishless treatments in all ponds in 2003 and 2004. Each pond is represented by a shaded dot and a line indicating the difference in tadpole weight between the two treatments (solid line – significant difference; dashed line – non-significant difference). Treatment effects were significant in all ponds except Pond 3-04 but acted in opposite directions in different ponds; thus, it cannot be concluded that there was any significant treatment effect on tadpole weight. See text for a more detailed explanation.

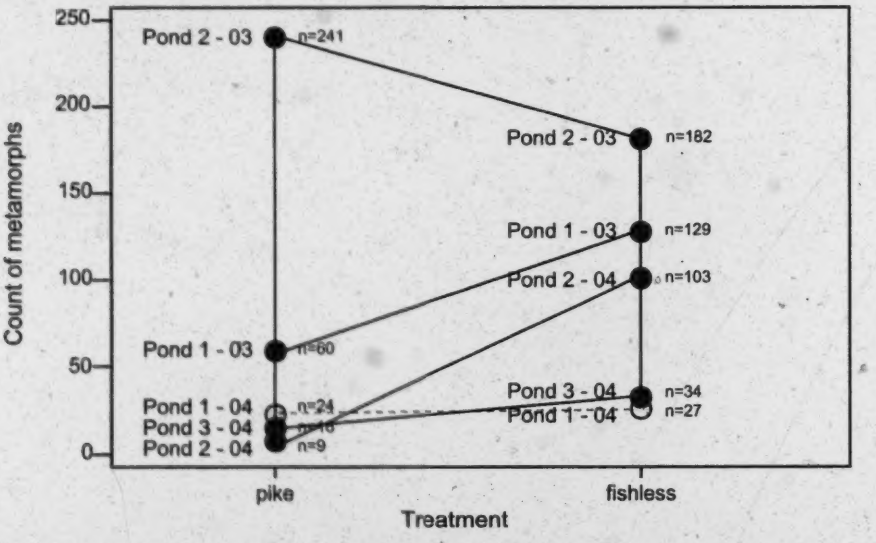

Figure 2-5. The count of metamorphs captured in both pike and fishless treatments in all ponds in 2003 and 2004. Each pond is represented by a shaded dot and a line indicating the difference in tadpole weight between the two treatments (solid line – significant difference; dashed line – non-significant difference). Pond 2-03 produced significantly more metamorphs in the pike treatment than in the fishless treatment. Ponds 1-03, 2-04 and 3-04 showed the opposite trend, with significantly more metamorphs emerging from the fishless treatment than the pike treatment. Pond 1-04 had no significant trend. See text for a more detailed explanation

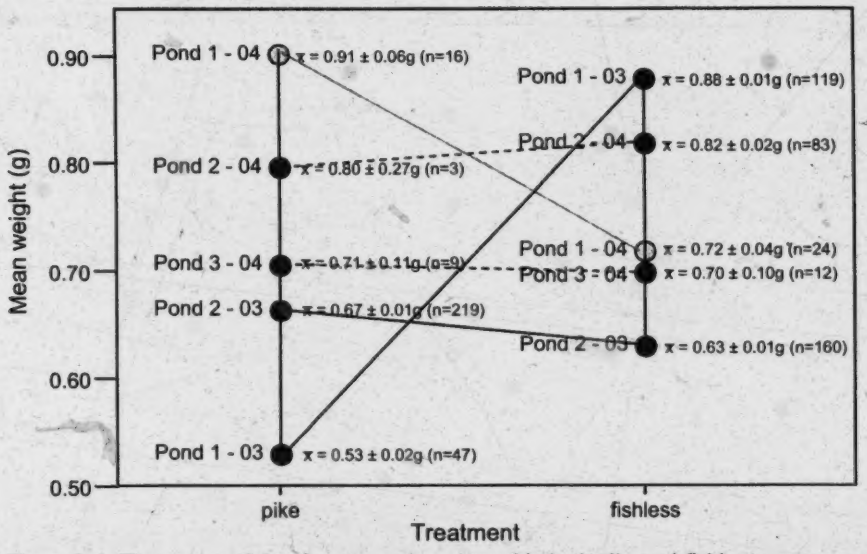

Figure 2-6. The mean weight of metamorphs captured in both pike and fishless treatments in all ponds in 2003 and 2004 during daily trapping in July and August. Each pond is represented by a shaded dot and a line indicating the difference in tadpole weight between the two treatments (solid line – significant difference; dashed line – non-significant difference). Treatment was significant in Pond 1-03, Pond 2-03 ,and Pond 1-04, but acted in opposite directions in the ponds, thus, it cannot be concluded that there was any significant treatment effect on metamorph weight. See text for a more detailed explanation.

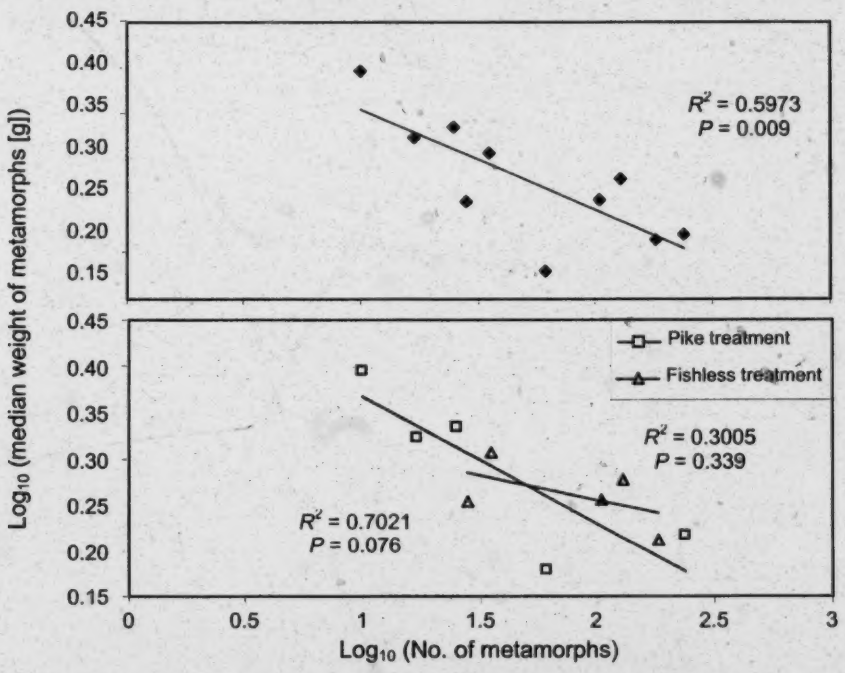

Figure 2-7. The relationship between median metamorph weight and metamorph density in (a) all ponds and (b) pike and fishless treatments. Each point represents a pond section in 2003 or 2004.

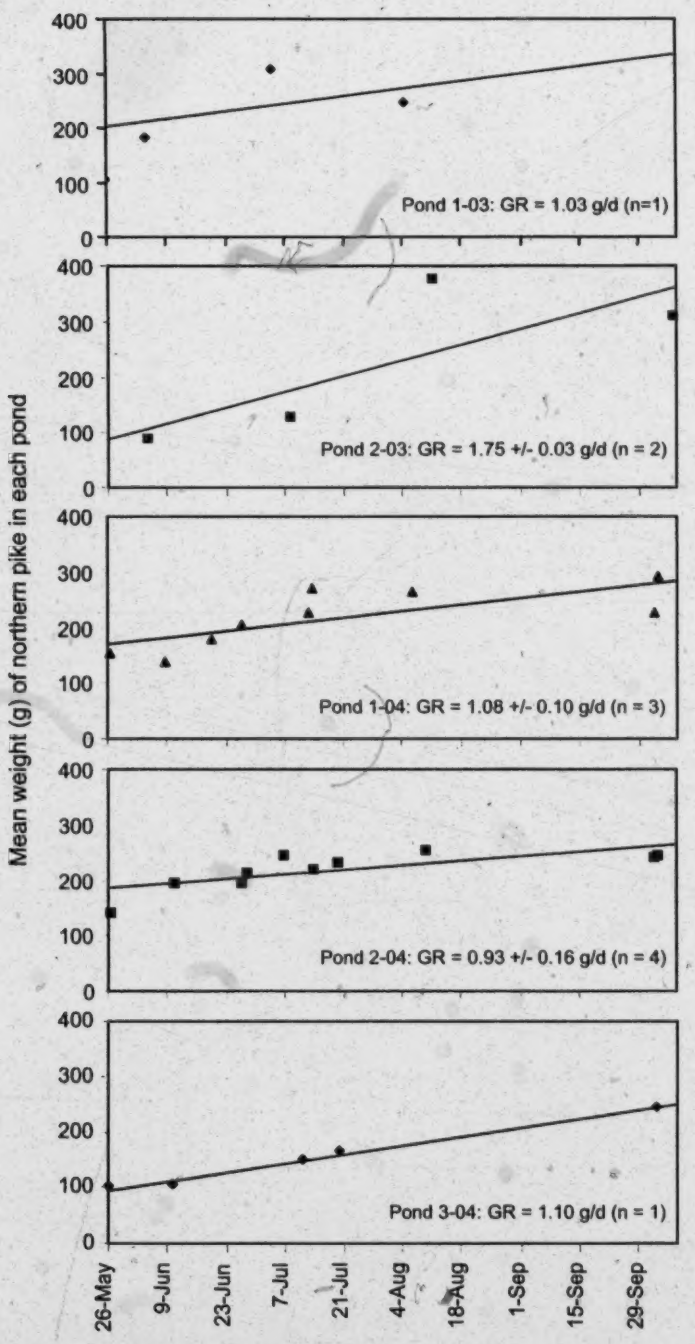

Figure 2-8. Mean change in weight of northern pike observed over time in each pond (growth rate [GR] per pond is displayed in parentheses; n is the number of fish used to calculate the mean growth rate).

Literature Cited

Alberta Sustainable Resource Development. 2006. Fisheries Management Information System: Stocking Report. ASRD, Edmonton, AB.

Anholt, B.R., E.E. Werner, and D.K. Skelly. 2000. Effect of food and predators on the activity of four larval ranid frogs. Ecology 81: 3509-3521.

Babbitt, K.J. 2001. Behaviour and growth of southern leopard frog *(Rana sphenocephala)* tadpoles: effects of food and predation risk. Canadian Journal of Zoology 79: 809-814.

Babbitt, K.J., M.J. Baber and T.L. Tarr. 2003. Patterns of larval amphibian distribution along a wetland hydroperiod gradient. Canadian Journal of Zoology 81: 1539-1552.

Beaudoin, C.P., W.M. Tonn, E.E. Prepas, and L.I. Wassenaar. 1999. Individual specialization and trophic adaptability of northern pike (*Esox lucius*): an isotope and dietary analysis. Oecologia 120: 386-396.

Berven, K.A. 1981. Mate choice in the wood frog, *Rana sylvatica*. Evolution 35: 707-722.

Berven, K.A. 1990. Factors affecting population fluctuations in larval and adult stages of the wood frog (Rana sylvatica). Ecology 71: 1599-1608.

Beyerle, G.B. 1971. A study of two northern pike - bluegill populations. Transactions of the American Fisheries Society 100: 69-73.

Biesterfeldt, J.M., J.W. Petranka and S. Sherbondy. 1993. Prevalence of chemical interference competition in natural populations of wood frogs, *Rana sylvatica*. Copeia 1993:688-695

Binckley, C.A. and W.J. Resetarits Jr. 2003. Functional equivalence of non-lethal effects: generalized fish avoidance determines distribution of gray treefrog, *Hyla chrysoscelis*, larvae. Oikos 102: 623-329.

Brönmark C. and L. Hansson. 2003. The biology of lakes and ponds. Oxford University Press, London.

Chalcraft, D.R. and W.J. Resetarits Jr. 2003. Predator identity and ecological impacts: functional redundancy or functional diversity. Ecology 84: 2407-2418.

Chapman, L.J., W.C. Mackay and C.W. Wilkinson. 1989. Feeding flexibility in northern pike (*Esox lucius*): fish versus invertebrate prey. Canadian Journal of Fisheries and Aquatic Science 46: 666-669.

Eaton B.R. 2004. The roles of landscape factors, predation, and demography in the ecology of anurans in boreal Alberta. Ph.D. Thesis, University of Alberta, Edmonton, Alberta , 176pp.

Eaton, B.R., W.M. Tonn, C.A. Paszkowski, A.J. Danylchuk and S.M. Boss. 2005. Indirect effects of fish winterkills on amphibian populations in boreal lakes. Canadian Journal of Zoology 83: 1532-1539.

Eklöv, P. and C. Halvarsson. 2000. The trade-off between foraging activity and predation risk for *Rana temporaria* in different food environments. Canadian Journal of Zoology 78: 734-739.

Eklöv, P. and E.E. Werner. 2000. Multiple predator effects on size-dependent behavior and mortality of two species of anuran larvae. Oikos 88: 250-258.

Fauth, J.E. 1990. Interactive effects of predators and early larval dynamics of the treefrog *Hyla chrysocelis*. Ecology 71: 1609-1616.

Gillespie G.R. 2001. The role of introduced trout in the decline of the spotted tree frog (*Litoria spenceri*) in south-eastern Australia. Biological Conservation 100: 187-198.

Gosner, K.L. 1960. A simplified table for staging anuran embryos and larvae with notes on identification. Herpetologica 16: 183-190.

Heath, D.D. and D.A. Roff. 1996. The role of trophic bottlenecks in stunting: a field test of an allocation model of growth and reproduction in yellow perch, *Perca flavescens*. Environmental Biology of Fishes 45: 53-63.

Hecnar, S.J. and R.T. M'Closkey. 1997. The effects of predatory fish on amphibian species richness and distribution. Biological Conservation 79: 123-131.

Herreid, C.F. and S. Kinney. 1966. Survival of Alaskan wood frog (*Rana sylvatica*) larvae. Ecology 47: 1039-1041.

Herreid, C.F. II and S. Kinney. 1967. Temperature and development of the wood frog *Rana sylvatica*, in Alaska. Ecology 48: 579-590.

Hopey, M.E. and J.W. Petranka. 1994. Restriction of Wood Frogs to Fish-Free Habitats: How Important Is Adult Choice? Copeia 1994: 1023-1025.

Howard, R.D. and A.G. Kluge. 1985. Proximate mechanisms of sexual selection in wood frogs. Evolution 39: 260-277.

Kats, L.B., J.W. Petranka and A. Sih. 1988. Antipredator Defenses and the Persistence of Amphibian Larvae With Fishes. Ecology 69: 1865-1870.

Kats, L.B. and L.M. Dill. 1998. The scent of death: Chemosensory assessment of predation risk by prey animals. Ecoscience 5: 361-394.

Knapp, R.A. and K.R. Matthews. 2000. Non-native fish introductions and the decline of the mountain yellow-legged frog from within protected areas. Conservation Biology 14: 428-438.

Knapp, R.A., K.R. Matthews, H.K. Preisler and R. Jellison. 2003. Developing probabilistic models to predict amphibian site occupance in a patchy landscape. Ecological Applications 13: 1069-1082.

Lardner, B. 1998. Plasticity or fixed adaptive traits? Strategies for predator avoidance in *Rana arvalis* tadpoles. Oecologia 117: 119-126.

Lardner, B. 2000. Morphological and life history responses to predators in larvae of seven anurans. Oikos 88: 169-180.

Light, R.W., P.H. Adler and D.E. Arnold. 1983. Evaluation of gastric lavage for stomach analyses. North American Journal of Fisheries Management 3: 81-85.

Macan, T.T. 1966. The influence of predation on the fauna of a moorland fishpond. Archiv für Hydrobiologie 61: 432-452.

Manitoba Conservation. 2005. 2005 Final Stock Report. Manitoba Conservation, Water Stewardship – Fisheries Branch. 5 pp.

Martinez, I.P., R. Alvarez and M.P. Herraez. 1996. Growth and metamorphosis of *Rana perezi* larvae in culture: effects of larval density. Aquaculture 142: 163-170.

McCollum, S.A. and J.D. Leimberger. 1997. Predator-induced morphological changes in an amphibian: predation by dragonflies affects tadpole shape and color. Oecologia 109: 615-621.

Morey, S. and D. Reznick. 2001. Effects of larval density on post metamorphic spadefoot toads (*Spea hammondii*). Ecology 82: 510-522.

Morin, P.J. 1983. Predation, competition, and the composition of larval anuran guilds. Ecological Monographs 53: 119-138.

Morin , P.J. 1985. Predation intensity, prey survival and injury frequency in an amphibian predator-prey interaction. Copeia 1985: 638-644.

Nelson, J.S. and M.J. Paetz. 1992. The fishes of Alberta. The University of Alberta Press, Edmonton.

Nicieza, A.G. 2000. Interacting effects of predation risk and food availability on larval anuran behaviour and development. Oecologia 123: 497-505.

Nyström, P. and K. Abjörnsson. 2000. Effects of fish chemical cues on the interactions between tadpoles and crayfish. Oikos 88: 181-190.

Nyström, P., O. Svensson, B. Lardner, C. Brönmark and W. Graneli. 2001. The influence of multiple introduced predators on a littoral pond community. Ecology 82: 1023-1039.

Nyström, P., L. Birkedal, C. Dahlberg and C. Brönmark. 2002. The declining spadefoot toad Pelobates fuscus: calling site choice and conservation. Ecography 25: 488-498.

Peacor, S. 2002. Positive effect of predators on prey growth rate through induced modifications of prey behaviour. Ecology Letters 5: 77-85.

Petranka, J.W., M.E. Hopey, B.T. Jennings, S.D. Baird and S.J. Boone. 1994. Breeding habitat segregation of wood frogs and American toads: The role of interspecific tadpole predation and adult choice. Copeia 1994:691-697.

Petranka, J.W. and C.A. Kennedy. 1999. Pond tadpoles with generalized morphology: is it time to reconsider their functional roles in aquatic communities? Oecologia 120:621-631.

Pilliod, D.S. and C.R. Peterson. 2001. Local and landscape effects of introduced trout on amphibians in historically fishless watersheds. Ecosystems 4: 322-333.

Puttlitz, M.H., D.P. Chivers, J.M. Kiesecker and A.R. Blaustein. 1999. Threat-sensitive predator avoidance by larval pacific treefrogs (Amphibia, Hylidae). Ethology 105: 449-456.

Richards, S.J. and C.M. Bull. 1990. Size-Limited Predation on Tadpoles of Three Australian Frogs. Copeia 1990: 1041-1046.

Robinson, C.L.K. and W.M. Tonn. 1989. Influence of environmental factors and piscivory in structuring fish assemblages of small Alberta lakes. Canadian Journal of Fisheries and Aquatic Science 46: 81-89.

Russell, A.P. and A.M. Bauer. 2000. The amphibians and reptiles of Alberta: a field guide and primer of boreal herpetology. University of Calgary Press, Calgary.

Saskatchewan Environment. 2004. Public Waters Anglers Guide, Stocked Waters 2004. Saskatchewan Environment, Environment and Resource Stewardship Division, Fish and Wildlife.10pp.

Schalk, G., M.R. Forbes and P.J. Weatherhead. 2002. Developmental plasticity and growth rates of green frog *(Rana clamitans*) embryos and tadpoles in relation to a leech *(Macrobdella decora*) predator. Copeia 2002: 445-449.

Semlitsch, R.D. and J.W. Gibbons. 1988. Fish predation in size-structured populations of treefrog tadpoles. Oecologia 75: 321-326.

Skelly, D.K. 1992. Field evidence for a cost of behavioral antipredator response in a larval amphibian. Ecology 73: 704-708.

Skelly, D.K. 1994. Activity level and the susceptibility of anuran larvae to predation. Animal Behaviour 47: 465-468.

Smith, D.C. 1983. Factors controlling tadpole populations of the chorus frog *(Pseudacris triseriata*) on Isle Royale, Michigan. Ecology 64: 501-510.

Smith, D.C. 1987. Adult recruitment in chorus frogs: effects of size and date at metamorphosis. Ecology 68: 344-350.

Smith, M.J., M.M. Drew, M. Peebles and K. Summers. 2005. Predator cues during the egg stage affect larval development in the gray treefrog, *Hyla versicolor* (Anura: Hylidae). Copeia 5: 167-173.

Sokal, R.R. and F.J. Rohlf. 1995. Biometry : the principles and practice of statistics in biological research. New York: Freeman.

Tyler, T., W.J. Liss, L.M. Ganio, G.L. Larson, R. Hoffman, E. Deimling and G. Lomnicky. 1998. Interaction between introduced trout and larval salamanders (*Ambystoma macrodactylum*) in high-elevation lakes. Conservation Biology 12: 94-105.

Van Buskirk, J. and K.L Yurewicz. 1998. Effects of predators on prey growth

rate: relative contributions of thinning and reduced activity. Oikos 82: 20-28.

Venturelli, P.A. 2004. Responses of northern pike and their macroinvertebrate prey to manipulation: a study of predation, winterkill, and food dynamics in boreal lakes. MSc, Thesis, University of Alberta, Edmonton, Alberta , 74pp.

Venturelli, P.A. and W.M. Tonn. 2005. Invertivory by northern pike (*Esox lucius*) structures communities of littoral macroinvertebrates in small boreal lakes. Journal of the North American Benthological Society 24: 904-918.

Werner, E.E. 1991. Nonlethal effects of a predator on competitive interactions between two anuran larvae. Ecology 72: 1709-1720.

Wilkinson, L. and G. Berg. 2004. Researching Amphibian Numbers in Alberta (RANA): 2004 provincial summary. Alberta Sustainable Resource Development, Fish and Wildlife Division, Alberta Species at Risk Report No. 95. Edmonton, AB.

Wilkinson, L. and K. Kempin. 2004. Researching Amphibian Numbers in Alberta (RANA): 2003 provincial summary. Alberta Sustainable Resource Development, Fish and Wildlife Division, Alberta Species at Risk Report No. 83. Edmonton, AB.

CHAPTER 3: Do fluctuations in northern pike (*Esox lucius*) density affect local wood frog (*Rana sylvatica*) abundance in a boreal Alberta lake?

Introduction

Winterkill is the mortality of fish and other aquatic animals caused by depletion of dissolved oxygen in a waterbody under the ice over winter. The extent of oxygen depletion is primarily associated with productivity and depth of the waterbody (Greenbank 1945, Mathias and Barica 1980) and many boreal lakes in Alberta are subject to winterkill due to their small size, shallow depth, and relatively high productivity. Unpredictable factors, such as duration of ice cover, depth of snow cover, and lake water levels can also be an influence (Greenbank 1945, Danylchuk and Tonn 2003). Because of the unpredictable nature of winterkill events, and the difficulty in detecting such events (as the conditions and consequences occur under the ice), studying the effects of winterkill can be difficult.

Small boreal lakes (i.e., < 400 ha) tend to contain a fish assemblage dominated by either large-bodied piscivores (i.e., northern pike [*Esox lucius*], yellow perch [*Perca flavescens*]) or small-bodied fish (i.e., fathead minnow [*Pimephales promelas*], brook stickleback [*Culaea inconstans*] and finescale dace [*Phoxinus neogaeus*]). The predator-prey relationship between large-bodied piscivores and small-bodied fish separates these fish into two assemblages in small lakes in boreal Alberta (Robinson and Tonn 1989, Paszkowski and Tonn 2000). Winter oxygen depletion also plays a part in structuring fish assemblages

in boreal lakes (Tonn and Magnuson 1982, Robinson and Tonn 1989) as small-bodied fish often have behavioural and physiological adaptations which allow them to survive hypoxic conditions (Gee et al. 1978, Klinger et al. 1982, Magnuson et al. 1985), while large-bodied fish are less able to adapt to hypoxic conditions and are more susceptible to winterkill (Tonn and Magnuson 1982). Both groups, however, may experience full or partial winterkill, resulting in fluctuations in the density of a fish population from year to year. Lakes that are regularly subjected to winterkill are typically fishless. In surveys of small boreal lakes in Alberta, approximately 52% are dominated by small-bodied fish and 27% of the lakes are dominated by large-bodied fish, leaving 21% of the lakes fishless (n = 102; size range: 1.7 to 362 ha; W.M. Tonn unpublished data).

In addition to the negative density effects, direct ecological effects of winterkill have been documented on the life history of large- and small-bodied fish populations (Fox and Keast 1991, Danylchuk and Tonn 2006) as well as the size structure (Danylchuk and Tonn 2003) and behaviour and distribution (Magnuson et al. 1985) of small-bodied fish. Secondary effects of winterkill have also been reported on prey organisms; winterkill depletion of large-bodied fish populations have resulted in increases in macroinvertebrate prey densities (Tonn et al. 2004). Other lake characteristics such as water clarity, and zooplankton biomass and size structure (Mittelbach et al. 1995, Zimmer et al. 2001) may also be indirectly affected by winterkill.

Stocking of sportfish into fishless lakes for recreational purposes has been a long-accepted practice. Northern pike are a very popular sportfish in the boreal

forest, and are often used for stocking in lakes in boreal Saskatchewan and Manitoba (Saskatchewan Environment 2004, Manitoba Conservation 2005). It is well-documented that the introduction of large predatory fish into a lake can have a negative effect on local amphibian richness and diversity (Hecnar and M'Closkey 1997, Smith et al. 1999), as well as amphibian distribution (Fisher and Shaffer 1996, Knapp et al. 2001, Matthews et al. 2001) and abundance (Bradford et al. 1993, Smith et al. 1999, Knapp and Matthews 2000, Gillespie 2001, Knapp et al. 2001, Pilliod and Peterson 2001, Babbitt et al. 2003), although the nature and strength of effects vary depending on the predator and prey species involved.

Eaton et al. (2005) investigated effects that winterkill had on local amphibian populations in several boreal lakes. They found that the abundance of wood frog (*Rana sylvatica*) metamorphs was greater following winterkill events, and suggested that increases were due to higher larval survival. This relationship was especially strong in fish communities dominated by small-bodied fish, but was also observed to a lesser extent in large-bodied fish communities.

Here I examine interactions between wood frog and northern pike in small boreal lakes, focusing on a 14 ha lake in boreal Alberta (LLB 100). The lake was fishless for at least 5 years (1996 – 2000) due to a suspected winterkill of fathead minnow, the only fish species present in the lake (Eaton 2004, W.M. Tonn and co-workers, unpublished data). In 2001, a population of northern pike was established in the lake, as part of a whole-lake experiment investigating the effect of pike invertivory on the macro-invertebrate community and the subsequent dietary and growth response of the pike themselves (Venturelli 2004). For this

experiment, efforts were made to avoid winterkill conditions and allow the population to overwinter successfully into 2002. In 2003, pike were still present in this lake, but by 2004 no fish were collected from the lake, suggesting that a winterkill over the winter of 2003-2004 had greatly reduced or eliminated the northern pike population. Thus, from 1996 to 2004, the lake had shifted from a fishless state to a piscivorous state, and (possibly) back to a fishless state again. From 1996 to 2004, the wood frog population was monitored around the lake. Amphibian populations of two nearby lakes (LLB 20 and LLB 800) that contained northern pike were also monitored from 1996 to 2004. These lakes were two of the piscivore lakes sampled in Eaton et al. (2005). Amphibian abundance data from these lakes were compared to LLB 100.

The aim of this study was to gain an understanding of the impact of pike stocking on local wood frog abundance, focusing on two objectives: a) to establish whether wood frog abundance was related to pike status in the manipulated lake (LLB 100) and b) to determine if wood frog abundance in LLB 100 varied more and/or had a different year-to-year variation than the unmanipulated lakes (LLB 20 and LLB 800). Both adult and metamorphic wood frog abundances were investigated: changes in metamorph abundance in response to pike status would suggest a change in recruitment, while changes in adult abundance would imply a change in immigration of breeding adults in response to the presence/absence of pike.

Methods and Materials

Description of lakes.

All study lakes (LLB 100, LLB 20 and LLB 800) were located within the boreal eco-region of northern Alberta (55°1' N, 111°7' W). Lake access was limited to all-terrain vehicles. All lakes were moderately small (surface area: LLB 100 - 14 ha; LLB 20 - 62 ha; LLB 800 - 105 ha), shallow (maximum depth: LLB 100 - 6.0 m; LLB 20 - 5.8 m; LLB 800 - 8.7 m) and naturally eutrophic (total phosphorus: LLB 100 - 64 µg/L; LLB 20 - 47 µg/L; LLB 800 - 48 µg/L; data from Prepas et al. 2001).

LLB 100 had been fishless during the first 5 years of monitoring due to a suspected winterkill (Eaton 2004, W. Tonn and co-workers, unpublished data). In May 2001, 355 northern pike (mean total length = 587 ± 2.5 mm) were stocked into LLB 100 (Venturelli 2004). Over the winter of 2001-2002, efforts were made to prevent winterkill of the stocked pike population (including removal of snow from ice surface to increase light penetration, and artificial aeration of the water to increase oxygen content; Greenbank 1945). No winterkill prevention efforts were employed in the winters of 2002 and 2003. From 2001 to 2004, the pike population in LLB 100 was monitored using gill-nets, minnow trapping and angling. From 2001 to 2003, northern pike were captured readily using these methods. In addition, in 2002 pike were observed spawning (P.Venturelli, personal communication), and a young-of-the-year (YOY) pike (total length = 166 mm) was captured in 2003 (K. Norris, personal observation), indicating that successful reproduction was occurring. No pike were observed or captured in

2004, suggesting that the population had declined or disappeared, likely due to winter hypoxia.

Fish populations in LLB 20 and 800 were monitored from 1995 to 1998 using overnight gill-netting (Eaton et al. 2005), and sampled again in 2004 using gill-nets and minnow traps. These lakes did suffer some winterkill, but typically had a fish assemblage dominated by northern pike and yellow perch.

Amphibian monitoring.

Amphibian species present in or around the study lakes were wood frog, striped chorus frog (*Pseudacris maculata*), Canadian toad (*Bufo hemiophrys*) and western toad (*Bufo boreas boreas*). Amphibian monitoring took place at all three lakes from 1996 to 2004.

From the period of 2000 to 2004, which coincided with the pike-stocking manipulation in LLB 100, the abundance of adult and metamorphic wood frogs was monitored at all three lakes using two grids of pitfall traps and drift fences located on either side of the lake, approximately 100 m from shore. Each grid consisted of 5 sets of pitfall-trap arrays spaced 40 m apart, parallel to the lake shore. Each array consisted of three pitfall traps spaced 5 m apart, connected by a 0.5 m high drift fence, shaped to form a 'V' with the open side facing the lake. Traps were constructed of metal cans (25 cm deep and 15 cm in diameter) with plastic funnels (12 cm deep and 15 cm in diameter) placed inside. A rock and wet moss were placed inside each trap, to provide moisture and shelter for captured amphibians. In addition, a stick was placed in the pitfall trap to provide a method of escape for any small mammals that were captured accidentally. Traps were

checked every 1-2 weeks between June 6 and August 29. Captured amphibians were identified, assigned to an age class (metamorph [≤27 mm snout-to-urostyle length, SUL] or adult [>27 mm SUL]; Eaton et al. 2005) and released. Captures were standardized as the number of individuals captured every 100 trap nights. Trapping effort averaged 1815 trap nights/year (range: 1240 to 2302 trap nights/year). No trapping occurred at LLB 20 or LLB 800 in 2003.

From 1996 to 1998, amphibian monitoring at all three lakes took place over two trapping periods: 'early' summer (May - June) and 'late' summer (August; Hannon et al. 2002). Trapping dates in 2000 to 2004 overlapped with the 'late' trapping period in 1996 to 1998, so only data from this trapping period was used in the analysis. Late pitfall trapping averaged 199 trap nights/year (range: 174 to 240 trap nights/year) and occurred for one week between August 11 and August 26. Trapping procedures were similar to those described above (see Eaton et al. 2005 for a detailed explanation).

Data Analysis.

Statistical analyses were performed on the abundances of both adult and newly metamorphosed wood frog using catch per unit effort (CPUE) over 100 pitfall-trap nights.

Pike manipulation (2000 to 2004)

To determine whether wood frog abundance in LLB 100 varied significantly due to pike status, CPUE data collected over the summer from 2000 to 2004 were log transformed and analyzed using a 1-way ANOVA with repeated measures (with year as the main factor). Tukey's pairwise comparisons were

used to determine significant differences between years. Sampling effort and sampling time was similar each year.

To determine if wood frog abundance in LLB 100 had a similar year-to-year variation as the other unmanipulated piscivore lakes, CPUE from all three lakes (LLB 100, LLB 20 and LLB 800) were compared for each year that sampling occurred. CPUE data collected over the summer were log transformed and analyzed using a 1-way ANOVA with repeated measures (with lake as the main factor). ANOVAs were performed for each year of the pike-stocking manipulation except 2003, as sampling did not occur in LLB 20 or 800 that year.

Long-term sampling (1996 to 2004)

To examine the long-term variation in wood frog abundance in LLB 100 during fishless and pike-stocked years, August CPUE during the fishless years (1996, 1997, 1998, 2000) and August CPUE during the pike-stocked years (2001, 2002, 2003, 2004) were log transformed and compared using a t-test. Finally, to determine if the long-term variation observed in LLB 100 from 1996 to 2004 was similar to the variation occurring in the two other study lakes, August CPUE data collected every year (excluding 1999, 2003) from each of the three lakes, were log transformed and analyzed using 1-way ANOVA with repeated measures (with lake as the main factor).

Results

Table 3-1 summarizes the dates of first metamorphosis (i.e., the date metamorphs were first observed), and the dates of peak metamorphosis (i.e., the date when the largest number of metamorphs was trapped) for each year, based on

weekly trapping. The date of first metamorphosis during pike stocking in LLB 100 appeared to be earlier than during the fishless years; however, I was not able to analyze this trend statistically given the low sample size (n = 5). The table also summarizes the state of the fish population in LLB 100 from 1996 to 2004.

Metamorph abundance.

Pike manipulation (2000 to 2004)

Sampling from 2000 to 2004 captured metamorphs in July and August. In LLB 100, metamorphs were first trapped in mid-July (July 12 to July 18), with peak captures occurring approximately one week later (Figure 3-1a). Sampling in 2002 did not begin until July 17 and possibly missed the peak metamorph emergence. Ignoring 2002, peak metamorph abundance was lowest in 2004 and highest in 2000. Metamorph abundance in LLB 100 differed significantly from year to year (F (4,14) = 5.07, P = 0.010); however, much of this difference was due to the low abundance of metamorphs in 2002. Metamorph abundance in 2002 was slightly lower than 2000 (P = 0.078), significantly lower than 2001 (P = 0.023) and 2003 (P = 0.016) but not different than 2004. Abundance in 2004 was slightly lower than 2003 (P = 0.082).

Overall, metamorph abundance in LLB 100 tended to be higher than in either LLB 20 or LLB 800 across all years (Figure 3-1). In LLB 800, metamorph emergence began in mid-July (July 11 to July 19); in LLB 20 metamorph emergence began later (July 14 to Aug 8). Unlike patterns in LLB 100, it was often difficult to distinguish a peak in the abundance of metamorphs in LLB 20

and LLB 800, possibly due to consistently low abundance of wood frogs or late metamorph emergence.

There was no difference between the abundance of metamorphs among lakes in 2000 (F (2,8) = 2.53, P = 0.141), and only a slight difference in 2001 (F (2,6) = 4.75, P = 0.058). A significant difference in the abundance of metamorphs among lakes was observed in 2002 (F (2,6) = 6.26, P = 0.034) and 2004 (F (2,9) = 13.13, P = 0.002). Metamorph abundance was not significantly different in LLB 100 than in LLB 800 in 2000 (P = 0.728) or 2001 (P = 0.134) but was significantly higher in 2002 (P = 0.046), and significantly lower in 2004 (P = 0.037). Metamorph abundance in LLB100 was not significantly different than LLB 20 in 2000 (P = 0.128), and was only slightly higher in 2001 (P = 0.102), 2002 (P = 0.056) and 2004 (P = 0.099). Metamorph abundance in LLB 20 was not significantly different from LLB 800 in 2000 (P = 367), 2001 (P = 979) or 2002 (P = 985), however, abundance was significantly lower in 2004 (P = 0.002).

Long-term sampling (1996 to 2004)

When examining abundance of wood frog metamorphs over a longer time period, abundance during the fishless years (1996 to 2000) was not significantly different from abundance during the pike-stocking years (2001 to 2004; Independent t-test: t = 0.115, df = 6, P = 0.914; Figure 3-2a). The abundance of metamorphs was not found to differ significantly among the three study lakes from 1996 to 2004 (excluding 1999 and 2003; F (2,12) = 1.46, P = 0.271; Figure 3-2).

Adult abundance.

Pike manipulation (2000 to 2004)

Adult wood frogs were captured on all lakes in all months throughout the summer from 2000 to 2004 (Figure 3-3). Adult abundance in LLB 100 differed significantly from year to year (F (4,19) = 5.75, P = 0.003). Adult abundance in 2000, when the lake was still fishless, did not differ significantly from 2001 or 2002. In 2003, however, when the lake still supported a moderate population of northern pike, adult abundance was significantly lower than in 2000 (P = 0.009), and in 2001 (P = 0.010), but not different from 2002. Adult abundance was also significantly lower in 2004 than in 2000 (P = 0.021) and in 2001 (P = 0.021) but not significantly different from 2002 or 2003.

Adult abundance differed significantly among the three study lakes in 2000 (F (2,14) = 12.94, P = 0.001), 2002 (F (2,6) = 9.98, P = 0.012) and 2004 (F (2,14) = 4.86, P = 0.025; but not 2001 [F (2,10) = 2.49, P = 0.132]). Adult abundance was significantly lower in LLB 100 than in LLB 800 in 2000 (P = 0.007) and 2002 (P = 0.010), and slightly lower in 2004 (P = 0.096). Adult abundance in LLB100 was not significantly different from LLB 20 in any year. Adult abundance in LLB 20 showed a similar trend to LLB 100 with significantly lower abundance than LLB 800 in 2000 (P = 0.001) and 2004 (P = 0.021), and slightly lower abundance than in 2002 (P = 0.092).

Long-term sampling (1996 to 2004)

Adult wood frog abundance did not differ significantly between the fishless years and the pike-stocked years (Independent t-test: t = 0.703, df = 6, P = 0.508;

Figure 3-4a) in LLB 100 in August from 1996 to 2004. Adult abundance in August did not differ significantly among the three lakes from 1996 to 2004 (excluding 1999 and 2003; $F(2,12) = 1.29$, $P = 0.311$; Figure 3-4).

Discussion

This study showed that abundances of wood frog varied substantially between boreal lakes that contained piscivorous fish, and from year to year on individual lakes. However, there was no evidence that stocking northern pike into a fishless boreal lake had strong effects on local wood frog abundance. My results are similar to Eaton et al. (2005) who documented dramatic fluctuations in metamorph wood frog abundance in lakes that contained piscivorous fish, but were unable to pinpoint a consistent effect of the abundance of piscivorous fish, which varied substantially in response to winterkills.

From 2000 to 2004, there was no significant difference in metamorph abundance in LLB 100 (except in 2002, when sampling was initiated later in the season). Similarly, August-only trapping data from LLB 100 over a 9-year period showed no significant difference between the abundance of metamorphs during the fishless years (1996 to 2000) and the abundance during the period associated with pike stocking (2001 to 2004). Likewise, during this 9-year period, there was no significant difference between the August-only abundance of metamorphs in LLB 100 and the abundance in the two other study lakes. In fact, the number of metamorphs appears to have increased after the stocking of pike in LLB 100, relative to the other study lakes (in 2001 and 2002).

Eaton et al. (2005) found that the presence of small-bodied fish negatively affected the abundance of wood frog metamorphs, likely through competition and predation on eggs and larvae. Given their size, small-bodied fish have a greater ability to enter structured inshore habitats where tadpoles seek refuge from predation (e.g., vegetated areas, undercut banks, etc). Northern pike, on the other hand, may be unable to access tadpole refuges due to their larger size, thereby limiting pike's ability to affect tadpole densities. Juvenile pike are very small when they hatch (~ 1 cm; Nelson and Paetz 1992) and may have been able to access tadpole refuges early in the spring. However, they grow very quickly, especially in their first year (Clark and Steinbach 1959), so their access to the tadpole refuges may be quickly limited by their size.

The abundance of adult wood frogs also did not appear to be affected by the presence/absence of northern pike. Adult abundance in LLB 100 was significantly higher in 2000, 2001 and 2002 than in 2003 and 2004, suggesting that adult abundance was not related to the presence/absence of pike. Similarly, there was no significant difference in August-only adult captures from LLB 100 between the fishless years (1996 to 2000) and the pike-stocked years (2001 to 2004), or between LLB 100 and the two other study lakes during a 9-year period. Adult abundance in LLB 100 was significantly lower than in LLB 800 in several years, while equal to adult abundance in LLB 20 in all years.

It is not surprising that adult wood frog abundance was not measurably affected by the presence/absence of northern pike. Although northern pike are known to prey on adult wood frogs, due to their terrestrial nature, adults are less

susceptible to predation than aquatic organisms and are only at risk of predation during spring breeding. Although a number of studies have suggested that adult amphibians of some species assess sites for the presence and density of fish before preferentially selecting fishless waterbodies in which to breed (Resetarits and Wilbur 1989, Hopey and Petranka 1994, Binckley and Resetarits 2002, 2003), this did not appear to be the case in these lakes. Since adult and metamorphic wood frogs were captured at all three lakes in all years (with no significant differences in abundance related to pike presence), it appears that adult wood frogs likely breed indiscriminately in lakes, regardless of presence/absence of fish (Eaton et al. 2005, Laurila and Aho 1997).

Large year-to-year and regional fluctuations are common in amphibian populations (Berven 1990, Pechmann and Wilbur 1994, Berven 1995, Green 2003). Variations in amphibian abundance may be affected by environmental conditions (e.g., low water temperatures and late ice-out [Herreid and Kinney 1967], regional moisture and low precipitation [Semlitsch 2002]). In fact, the lowest mean precipitation values between 1996 and 2004 were recorded in 1998 and 2002, two years when the abundance of metamorphs in all three lakes was also the lowest (using historical climate data recorded at a data station in nearby Lac La Biche by Environment Canada). Regionally, amphibian abundance may be affected by changes in the pH of a waterbody (Banks and Beebee 1988, Russell and Bauer 2000).

Local variation in wood frog abundance may also be related to the presence of other amphibian species. Canadian and boreal toads are both found in the Lac

la Biche area, and use breeding sites and larval food resources similar to those of wood frogs (Russell and Bauer 2000). In fact, wood frogs and toad species were not often found in large numbers at the same lake (K. Norris, personal observation). Toads were rarely captured at LLB 100 (only 5 metamorph toads and only 12 adult toads were caught during the entire monitoring period), while moderate toad abundance has been reported regularly at LLB 20 (Eaton et al. 2005).

This study did not investigate whether the presence of northern pike affected the size of the emerging metamorphs, although the timing of metamorphosis may have been earlier once the pike population was established in LLB 100 (although this trend is questionable). If the date of first metamorphosis is earlier due to the presence of fish, wood frog metamorphs may be emerging from the lakes at a smaller size, which could have implications for their survival into their terrestrial stage (Berven 1981, Howard and Kluge 1985, Smith 1987, Berven 1990, Morey and Reznick 2001).

Northern pike are known to be indiscriminate predators, feeding opportunistically on a wide range of prey (Beaudoin et al. 1999, Venturelli and Tonn 2005); in fact tadpoles were found in the stomach contents of pike in LLB 100 (Venturelli and Tonn 2005). So, why did the stocked northern pike not affect the local wood frog population, especially the numbers of emerging metamorphs? One explanation discussed earlier is tadpoles' use of refuges not accessible to pike. Another explanation is the pike's choice of prey. LLB 100 likely contained large populations of macroinvertebrates (e.g., Odonata and Coleoptera larvae,

Amphipoda, as well as Hirudinea), which had thrived in the fishless lake for many years and provided the main food source for the introduced pike (Venturelli and Tonn 2005). Interactions between these macroinvertebrate predators and tadpoles may also have been important; tadpole avoidance and anti-predator behaviour in response to macroinvertebrate predators may have also acted to avoid predation by pike. These hypotheses are not necessarily mutually exclusive, but do require further investigation.

Conclusion

Changes in boreal piscivore populations occur due to winterkill or stocking. While fluctuations in small-bodied fish species have been shown to impact local wood frog populations in boreal Alberta (Eaton et al. 2005), my study did not find any evidence to support the claim that the introduction of northern pike into boreal lakes negatively affects local wood frog populations. Although both adult and metamorphic wood frog abundance varied from year to year in LLB 100, I found no evidence that these variations were caused by the presence or abundance of pike. Other factors may have played a part in affecting wood frog abundance (food-web interactions, natural fluctuations in anuran abundance due to environmental factors) and it appears that boreal wood frog populations readily survive large year-to-year variations in abundance.

A future study is recommended to explore whether tadpole avoidance behaviour and use of refuges increases in the presence of northern pike. An investigation into whether the timing of metamorphosis and metamorph size is affected by the presence/absence of northern pike (results from the pond

experiment [i.e., Chapter 2] were inconclusive) would also be of interest. Examining changes in adult and metamorph abundance in response to yearly fluctuations in macroinvertebrate diversity and density could be done using similar procedures as this study.

My study found no evidence to suggest that stocking of pike into a fishless boreal waterbody had a detrimental effect on either the local adult or metamorphic wood frog abundance. These results are contrary to other studies, which have found sportsfish to reduce or eliminate some amphibian species in stocked lakes (Pilliod and Peterson 2000), resulting in fisheries managers reconsidering their stocking practices (Fraley 1996). As a result, I am reluctant to conclude that northern pike have no effect on the local amphibian population, especially since specific effects on tadpole activity and survivorship have been documented in smaller ponds (Chapter 2).

Table 3-1. Summary dates of metamorphosis in all three study lakes from 1996 to 2004.

	Date of first emergence		
	LLB 100[b]	LLB 20	LLB 800
1996[a]	n/a	n/a	n/a
1997[a]	n/a	n/a	n/a
1998[a]	n/a	n/a	n/a
1999	not sampled	not sampled	not sampled
2000	18-Jul	1-Aug	19-Jul
2001	12-Jul	8-Aug	11-Jul
2002	23-Jul	23-Jul	31-Jul
2003	14-Jul	not sampled	not sampled
2004	15-Jul	14-Jul	14-Jul
	Date of peak emergence		
	LLB 100	LLB 20	LLB 800
1996[a]	n/a	n/a	n/a
1997[a]	n/a	n/a	n/a
1998[a]	n/a	n/a	n/a
1999	not sampled	not sampled	not sampled
2000	24-Jul	9-Aug	1-Aug
2001	23-Jul	8-Aug	8-Aug
2002	23-Jul	23-Jul	31-Jul
2003	17-Jul	not sampled	not sampled
2004	22-Jul	27-Jul	27-Jul

[a] in 1996 to 1998, lakes weren't sampled until mid August, after the peak in emerging metamorphs

[b] description of pike population in LLB 100:

1996 - fishless
1997 - fishless
1998 - fishless
1999 - fishless
2000 - fishless
2001 - stocked with northern pike
2002 - pike numbers actively maintained
2003 - pike present but numbers decreased
2004 - pike eliminated or drastically reduced by winterkill?

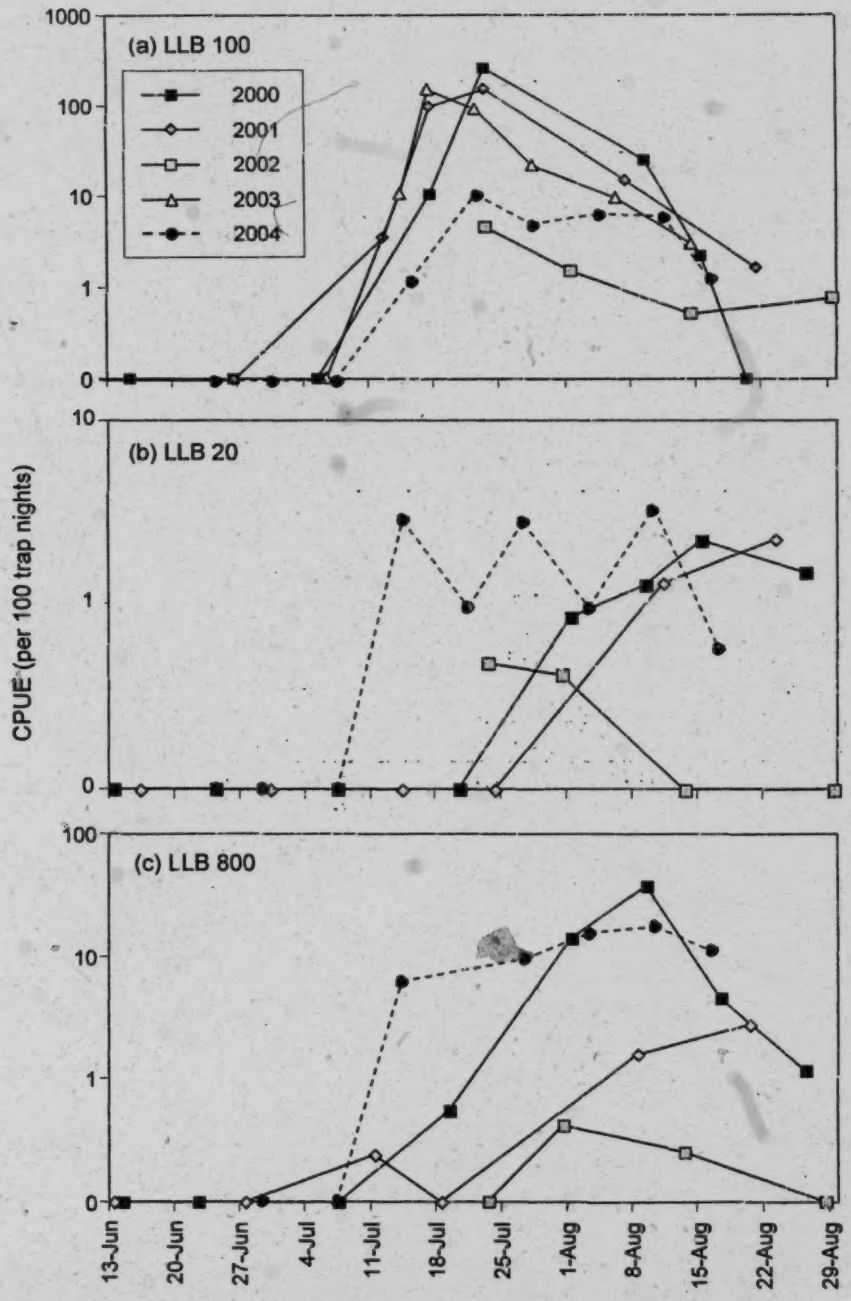

Figure 3-1: Change in metamorph abundance in three boreal lakes (LLB 100, LLB 20, LLB 800) over the summer months in years 2000 to 2004. All abundance is measured as CPUE per 100 trap nights. A log scale was used for the Y-axis. LLB 20 and LLB 800 were not sampled in 2003.

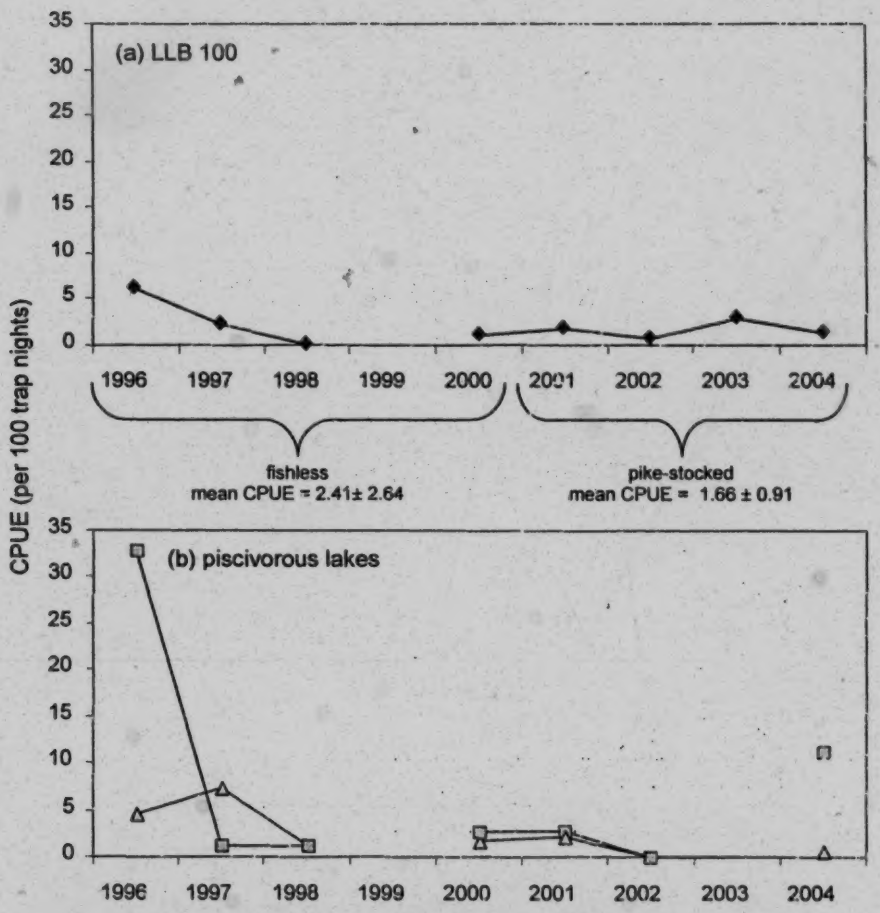

Figure 3-2: Change in metamorph abundance in August from 1996 to 2004 in (*a*) LLB 100, and (*b*) two additional piscivorous lakes (LLB 20 [△] and LLB 800 [□], respectively). All abundance is measured as CPUE per 100 trap nights. No lakes were sampled in 1999. LLB 20 and LLB 800 were not sampled in 2003.

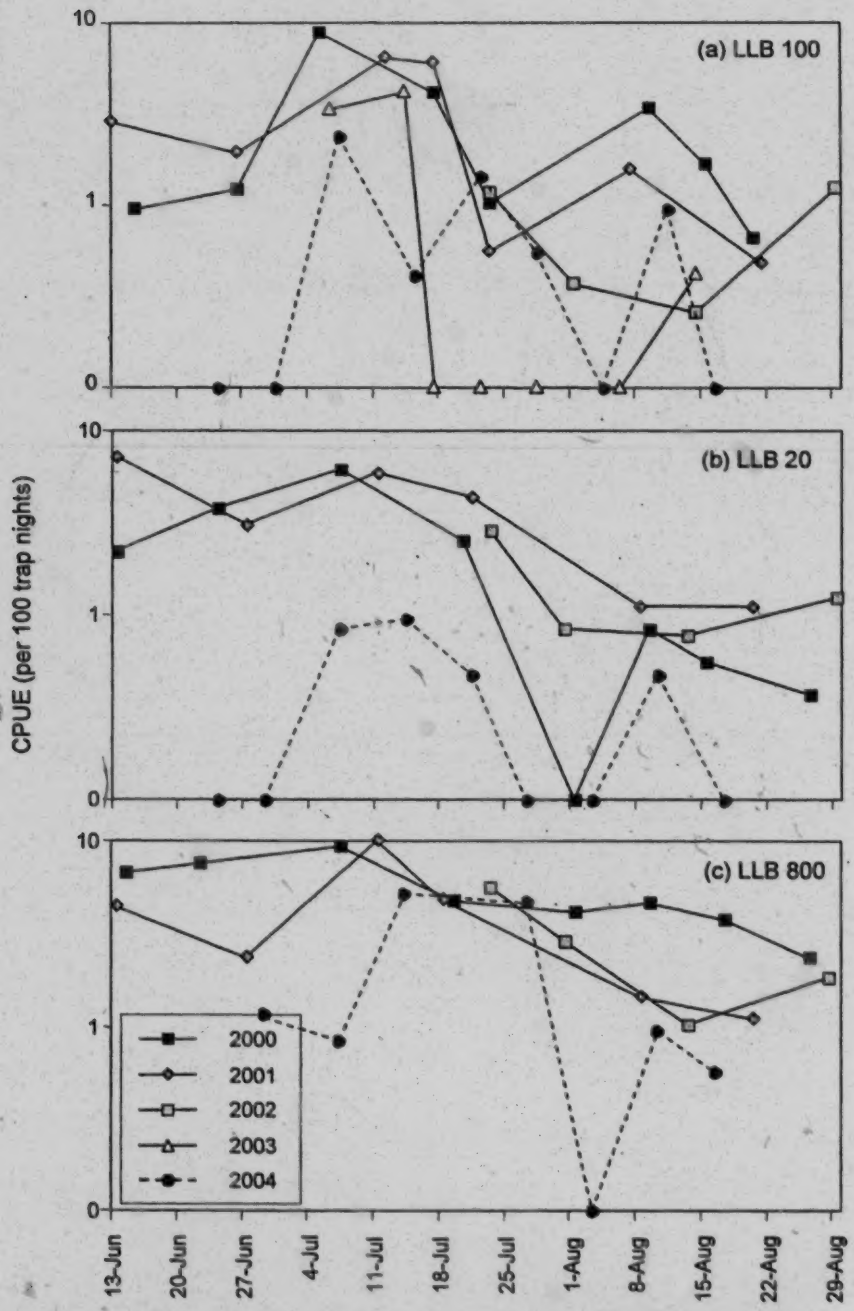

Figure 3-3: Change in adult abundance in three boreal lakes (LLB 100, LLB 20, LLB 800) over the summer months in years 2000 to 2004. All abundance is measured as CPUE per 100 trap nights. A log scale was used for the Y-axis. LLB 20 and LLB 800 were not sampled in 2003.

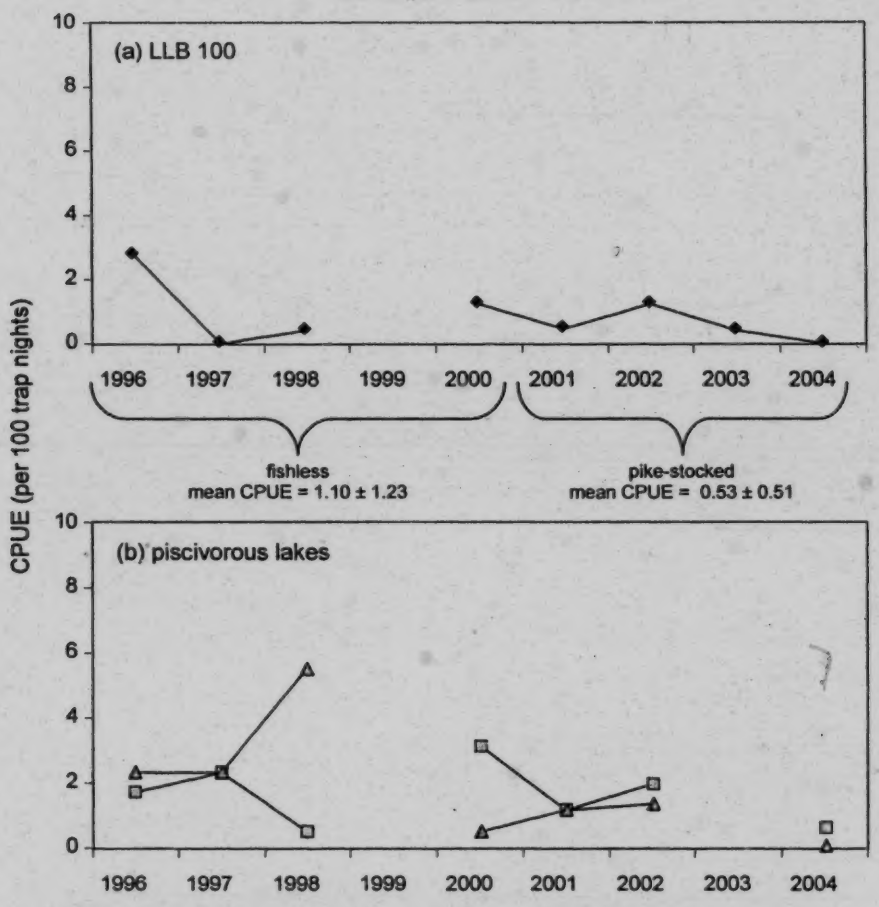

Figure 3-4: Change in adult abundance in August from 1996 to 2004 in (*a*) LLB 100, and (*b*) two additional piscivorous lakes (LLB 20 [Δ] and LLB 800 [□], respectively). All abundance is measured as CPUE per 100 trap nights. No lakes were sampled in 1999. LLB 20 and LLB 800 were not sampled in 2003.

Literature Cited:

Babbitt, K.J., M.J. Baber and T.L. Tarr. 2003. Patterns of larval amphibian distribution along a wetland hydroperiod gradient. Canadian Journal of Zoology 81: 1539-1552.

Banks, B. and T.J.C. Beebee. 1988. Reproductive success of natterjack toads *Bufo calamita* in two contrasting environments. Journal of Animal Ecology 57: 475-492.

Beaudoin, C.P., W.M. Tonn, E.E. Prepas and L.I. Wassenaar. 1999. Individual specialization and trophic adaptability of northern pike (*Esox lucius*): an isotope and dietary analysis. Oecologia 120:386-396.

Berven, K.A. 1981. Mate choice in the wood frog, *Rana sylvatica*. Evolution 35: 707-722.

Berven, K.A. 1990. Factors affecting population fluctuations in larval and adult stages of the wood frog (*Rana sylvatica*). Ecology 71: 1599-1608.

Berven, K.A. 1995. Population regulation in the wood frog, *Rana sylvatica*, from three diverse geographic localities. Australian Journal of Ecology 71: 1599-1608.

Binckley, C.A. and W.J. Resetarits Jr. 2002. Reproductive decisions under threat of predation: squirrel treefrog (*Hyla squirella*) responses to banded sunfish (*Enneacanthus obesus*). Oecologia 130: 157-161.

Binckley, C.A. and W.J. Resetarits Jr. 2003. Functional equivalence of non-lethal effects: generalized fish avoidance determines distribution of gray treefrog, *Hyla chrysoscelis*, larvae. Oikos 102: 623-629.

Bradford, D.F., F. Tabatabai and D.M. Graber. 1993. Isolation of remaining populations of the native frog, *Rana muscosa*, by introduced fishes in Sequoia and Kings Canyon National Parks, California. Conservation Biology 7: 882-888.

Clark, C.F. and F. Steinbach. 1959. Observations on the age and growth of the northern pike, *Esox lucius* L., in East Harbour, Ohio. The Ohio Journal of Science 59: 129-134.

Danylchuk, A.J. and W.M. Tonn. 2003. Natural disturbances and fish: local and regional influences on winterkill of fathead minnows in boreal lakes. Transactions of the American Fisheries Society 132: 289-298.

Danylchuk, A.J. and W.M. Tonn. 2006. Natural disturbance and life history: consequences of winterkill on fathead minnow in boreal lakes. Journal of Fish Biology 68: 681-694.

Eaton, B.R. 2004. The roles of landscape factors, predation and demography in the ecology of anurans in boreal Alberta. Ph.D. thesis. University of Alberta, Edmonton. 176pp.

Eaton, B.R., W.M. Tonn, C.A. Paszkowski, A.J. Danylchuk and S.M. Boss. 2005. Indirect effects of fish winterkills on amphibian populations in boreal lakes. Canadian Journal of Zoology 83: 1532-1539.

Fisher, R.N., H.B. Shaffer. 1996. The decline of amphibians in California's Great Central Valley. Conservation Biology 10: 1387-1397.

Fox, M.G. and A. Keast. 1991. Effect of overwinter mortality on reproductive life history characteristics of pumpkinseed (*Lepomis gibbosus*) populations. Canadian Journal of Fisheries and Aquatic Sciences 48: 1792-1799.

Fraley, J. 1996. Cooperation and controversy in wilderness fisheries management. Fisheries. 21: 16-21.

Gee, J. H., R. F. Tallman, and H. J. Smart. 1978. Reactions of some great plains fishes to progressive hypoxia. Canadian Journal of Zoology 56: 1962-1966.

Gillespie G.R. 2001. The role of introduced trout in the decline of the spotted tree frog (*Litoria spenceri*) in south-eastern Australia. Biological Conservation 100: 187-198.

Green, D.M. 2003. The ecology of extinction: population fluctuation and decline in amphibians. Biological Conservation 111: 331-343.

Greenbank, J.T. 1945. Limnological conditions in ice-covered lakes, especially as related to winterkill of fish. Ecological Monographs 15: 343-392.

Hecnar, S.J. and R.T. M'Closkey. 1997 The effects of predatory fish on amphibian species richness and distribution. Biological Conservation 79: 123-131.

Herreid, C.F. II and S. Kinney. 1967. Temperature and development of the wood frog, *Rana sylvatica*, in Alaska. Ecology 48: 579-590.

Hopey, M.E. and J.W. Petranka. 1994. Restriction of wood frogs to fish-free habitats: how important is adult choice? Copeia 1994: 1023-1025.

Howard, R.D. and A.G. Kluge. 1985. Proximate mechanisms of sexual selection in wood frogs. Evolution 39: 260-277.

Klinger, S. A., J. J. Magnuson, and G. W. Gallepp. 1982. Survival mechanisms of the central mudminnow (*Umbra limi*), fathead minnow (*Pimephales promelas*) and brook stickleback (*Culaea inconstans*) for low oxygen in winter. Environmental Biology of Fishes 7: 113-120.

Knapp, R.A. and K.R. Matthews. 2000. Non-native fish introductions and the decline of the mountain yellow-legged frog from within protected areas. Conservation Biology 14: 428-438.

Knapp, R.A., K.R. Matthews, and O. Sarnelle. 2001. Resistance and resilience of alpine lake fauna to fish introductions. Ecological Monographs 71: 401-421.

Laurila, A. and T. Aho. 1997. Do female common frogs choose their breeding habitat to avoid predation on tadpoles? Oikos 78: 585-591.

Magnuson, J.J., A.L. Beckel, K. Mills and S.B. Brandt. 1985. Surviving winter hypoxia: behavioral adaptations of fishes in a northern Wisconsin winterkill lake. Environmental Biology of Fishes 14: 241-250.

Manitoba Conservation. 2005. 2005 Final Stock Report. Manitoba Conservation, Water Stewardship – Fisheries Branch. 5 pp.

Mathias, J.A. and J. Barica. 1980. Factors controlling oxygen depletion in ice-covered lakes. Canadian Journal of Fisheries and Aquatic Sciences 37: 185-194.

Matthews, K.R., K.L. Pope, H.K. Preisler and R.A. Knapp. 2001. Effects of nonnative trout on Pacific treefrogs (*Hyla regilla*) in the Sierra Nevada. Copeia 2001: 1130-1137.

Mittelbach, G.G., A.M. Turner, D.J. Hall, J.E. Rettig and C.W. Osenberg. 1995. Perturbation and Resilience: A Long-Term, Whole-Lake Study of Predator Extinction and Reintroduction. Ecology 76: 2347-2360.

Morey, S. and D. Reznick. 2001. Effects of larval density on post metamorphic spadefoot toads (*Spea hammondii*). Ecology 82: 510-522.

Nelson, J.S. and M.J. Paetz. 1992. The fishes of Alberta. The University of Alberta Press, Edmonton.

Paszkowski, C.A., and W.M. Tonn. 2000. Community concordance between the fish and aquatic birds of lakes in northern Alberta, Canada: the relative importance of environmental and biotic factors. Freshwater Biology 43: 421-437.

Pechmann, J.H.K., and H.M. Wilbur. 1994. Putting declining amphibian populations in perspective: natural fluctuations and human impacts. Herpetologica 50: 65-84.

Pilliod, D.S. and C.R. Peterson. 2000. Evaluating effects of fish stocking on amphibian populations in wilderness lakes. USDA Forest Proceedings RMRS-P-15-VOL-5: 328-335.

Pilliod, D.S. and C.R. Peterson. 2001. Local and landscape effects of introduced trout on amphibians in historically fishless watersheds. Ecosystems 4: 322-333.

Prepas, E.E., B. Pinel-Alloul, D. Planas, G. Méthot, S. Paquet, and S. Reedyk. 2001. Forest harvest impacts on water quality and aquatic biota on the

Boreal Plain: introduction to the TROLS lake program. Canadian Journal of Fisheries and Aquatic Science 58: 421-436.

Resetarits, W.J. and H.M. Wilbur. 1989. Choice of oviposition site by *Hyla chrysoscelis*: role of predators and competitors. Ecology 70: 220-228.

Robinson, C.L.K. and W.M. Tonn. 1989. Influence of environmental factors and piscivory in structuring fish assemblages of small Alberta lakes. Canadian Journal of Fisheries and Aquatic Sciences 46: 81-89.

Russell, A.P. and A.M. Bauer. 2000. The amphibians and reptiles of Alberta: a field guide and primer of boreal herpetology. University of Calgary Press, Calgary.

Saskatchewan Environment. 2004. Public Waters Anglers Guide, Stocked Waters 2004. Saskatchewan Environment, Environment and Resource Stewardship Division, Fish and Wildlife.10pp.

Semlitsch, R.D. 2002. Critical elements for biologically based recovery plans od aquatic-breeding amphibians. Conservation Biology 16: 619-629

Smith, D.C. 1987. Adult recruitment in chorus frogs: effects of size and date at metamorphosis. Ecology 68: 344-350.

Smith, G.R., J.E. Rettig, G.G. Mittelbach, J.L. Valiulis and S.R. Schaack. 1999. The effects of fish on assemblages of amphibians in ponds: a field experiment. Freshwater Biology 41: 829-837.

Tonn, W.M., P.W. Langlois, E.E. Prepas, A.J. Danylchuk and S.M. Boss. 2004. Winterkill cascade: indirect effects of a natural disturbance on littoral

macroinvertebrates in boreal lakes. Journal of the North American Benthological Society 23: 237-250.

Tonn, W.M and J.J. Magnuson. 1982. Patterns in the species composition and richness of fish assemblages in northern Wisconsin lakes. Ecology 63: 1149-1166.

Venturelli, P.A. 2004. Responses of northern pike and their macroinvertebrate prey to manipulation: a study of predation, winterkill, and food web dynamics in boreal lakes. M.Sc. thesis, University of Alberta, Edmonton. 92 pp.

Venturelli, P.A. and W.M. Tonn. 2005. Invertivory by northern pike (*Esox lucius*) structures communities of littoral macro invertebrates in small boreal lakes. Journal of the North American Benthological Society 24: 904-918.

Zimmer, K.D., M.A. Hanson and M.G. Butler. 2001. Effects of fathead minnow colonization and removal on a prairie wetland ecosystem. Ecosystems 2001: 346-357.

CHAPTER 4. General Summary and Conclusion

Large-bodied fish have a negative impact on both the aquatic (Macan 1966, Knapp and Matthews 2000, Gillespie 2001) and terrestrial (Bradford et al. 1993, Sjögren 1991, Semlitsch 1993) life stages of amphibian populations. My research focused on the interaction between northern pike and wood frogs in boreal Alberta. Using experimental ponds, I examined the effects of stocked northern pike on wood frog tadpole activity, development and survivorship. To accompany this experiment, I examined the effect of stocking of northern pike on local metamorph and adult wood frog abundance, using monitoring data at three boreal lakes over a 9-year period. My overall objective was to determine whether northern pike that were stocked into fishless waterbodies had a negative impact on the local wood frog population (both aquatic and terrestrial life stages).

I performed a manipulative experiment, using whole experimental ponds, to examine the direct and indirect effects of stocked northern pike on wood frog tadpole activity, development and survivorship. I found that stocked pike had a negative effect on tadpole activity and survivorship. These effects were indirect, as tadpoles were less active in the presence of pike. The effect was also direct, as tadpoles were found in the stomachs of two pike during the study, showing that tadpoles are a food source for pike.

I used data collected at three boreal lakes over a 9-year period in Alberta, to examine the effects of stocked northern pike on wood frog adult and metamorph abundance. I found that the stocking of pike into a fishless lake did not have a measurable impact on either metamorph or adult abundance. This

monitoring also showed that wood frog abundance varied from year to year, as well as from location to location.

Wood frogs use boreal lakes for breeding and may increase their use during periods of drought or low water when temporary ponds are unavailable, a situation which may become more common with predicted changes to the climate (Ovaska 1997, Schindler 2001). Based on the results from my pond experiments, it was suggested that northern pike in these lakes may negatively impact larval activity and survivorship, and decrease the quantity and quality of metamorphs emerging from that lake. However, the monitoring data indicated that stocked northern pike did not significantly impact the local wood frog population.

Although attempts were made to create a natural setting for the pond experiment, it is possible that performing an experiment, in which many factors were controlled, inadvertently introduced limitations which may have misrepresented or overlooked important features of the natural amphibian and pike community. The pond experiment demonstrated the effect that stocked pike have on wood frog tadpoles in a somewhat controlled setting. It's possible that the controlled conditions enabled or influenced the pike to have a negative interaction with the tadpoles that wouldn't have occurred in a larger natural environment. On the other hand, it is possible that the negative impacts of northern pike on wood frog tadpoles observed in the experiment do exist in boreal lakes but are not critical enough to translate into negative impacts on the local wood frog population as a whole.

In this study, the experimental ponds were tested at a smaller spatial and temporal scale than the lake monitoring. Scale is very important to consider in ecological studies (Carpenter 1996, Schindler 1998); specifically, venue has been documented to be an important factor when considering trends in amphibian studies (Skelly and Kiesecker 2001). Often, effects are found to be stronger in smaller experimental venues, than they actually are in field situations (Skelly 2002). Schindler (1998) noted that smaller-scale experiments often give results which, although are highly repeatable, are often misleading, and recommended whole-lake studies for realistic predictions of ecosystem processes. Based on this, is it reasonable to assume that the results from the lake monitoring provided a more realistic indication of the relationship between northern pike and wood frogs in boreal Alberta than the pond experiment?

This can be answered by further studies. One suggestion is to perform a similar experiment using mesh enclosures placed into boreal lakes, to see if the effects on tadpole activity and survivorship in the experimental ponds also occur in a lake setting. Another suggestion is to document whether specific predator-avoidance behaviour (i.e., spatial avoidance, use of refuges) and/or morphological phenotypic plasticity (i.e., change in fin/tail shape) are exhibited by wood frog tadpoles in the presence of pike, and investigate whether these behaviours and morphological changes occur in a lake setting. One objective that was not specifically investigated with the lake monitoring data is whether the stocking of pike into the lake affected the size of the emerging metamorphs or the timing of metamorphosis. Continued monitoring of wood frog and pike populations at

these boreal lakes would show long-term trends which may help provide insight on this issue.

While wood frog abundance may not be visibly impacted by stocked northern pike, other amphibian species may be more vulnerable. The western toad (*Bufo boreas*), the Canadian toad (*Bufo hemiophrys*), as well as the boreal chorus frog (*Pseudacris triseriata*), all inhabit the boreal forest and require waterbodies for egg-laying and larval development. Eaton et al. (2005) documented a dramatic increase in toad abundance following a winterkill in a piscivore lake. Future studies could investigate the impact of northern pike populations on the larval and terrestrial stages of these amphibian species.

Results from my research are conflicting and have not explained the relationship between wood frogs and stocked northern pike. The dissimilar views about the impact of pike on the local wood frog population makes it difficult to come to a broad conclusion and make any recommendations regarding this issue. Results from the pond experiment, as well as other studies, suggest that stocked predatory fish do impact local larval and adult amphibian populations; however, whether these impacts can be applied to northern pike and wood frogs in boreal Alberta lakes, remains to be seen. As a result, it is difficult to suggest a management approach for these boreal species. Future studies and longer-term monitoring may help to clarify this issue.

Literature Cited

Bradford, D.F., F. Tabatabai and D.M. Graber. 1993. Isolation of remaining populations of the native frog, *Rana muscosa*, by introduced fishes in Sequoia and Kings Canyon National Parks, California. Conservation Biology 7: 882-888

Carpenter, S.R. 1996. Microcosm Experiments have Limited Relevance for Community and Ecosystem Ecology. Ecology 77: 677--680.

Eaton, B.R., W.M. Tonn, C.A. Paszkowski, A.J. Danylchuk and S.M. Boss. 2005. Indirect effects of fish winterkills on amphibian populations in boreal lakes. Canadian Journal of Zoology 83: 1532-1539.

Gillespie G.R. 2001. The role of introduced trout in the decline of the spotted tree frog (*Litoria spenceri*) in south-eastern Australia. Biological Conservation 100: 187-198.

Knapp, R.A. and K.R. Matthews. 2000. Non-native fish introductions and the decline of the mountain yellow-legged frog from within protected areas. Conservation Biology 14: 428-438.

Macan, T.T. 1966. The influence of predation on the fauna of a moorland fishpond. Archiv für Hydrobiologie 61: 432-452.

Ovaska K. 1997. The vulnerability of amphibians in Canada to global warming and increased solar radiation. In *Amphibians in Decline. Canadian Studies of a Global Problem*, ed. DM Green. *Herpetological Conserv.*, Vol 1: 206-25.

Schindler, D.W. 1998. Whole-ecosystem experiments: replication versus realism: the need for ecosystem-scale experiments. Ecosystems 1: 323-334.

Schindler , D.W. 2001. The cumulative effects of climate warming and other human stresses on Canadian freshwaters in the new millennium. Canadian Journal of Fisheries and Aquatic Sciences 58: 18-29.

Semlitsch, D. 1993. Effects of different predators on the survival and development of tadpoles from the hybridogenetic *Rana esculenta* complex. Oikos 67: 40-46.

Sjögren, P. 1991. Extinction and isolation gradients in metapopulations: The case of the pool frog *(Rana lessonae)*. Biological Journal of the Linnean Society 42: 135-147.

Skelly, D.K. 2002. Experimental venue and estimation of interaction strength. Ecology 83: 2097–2101.

Skelly, D.K. and J.M. Kiesecker. 2001. Venue and outcome in ecological experiments: manipulations of larval anurans. Oikos 94: 198-208.